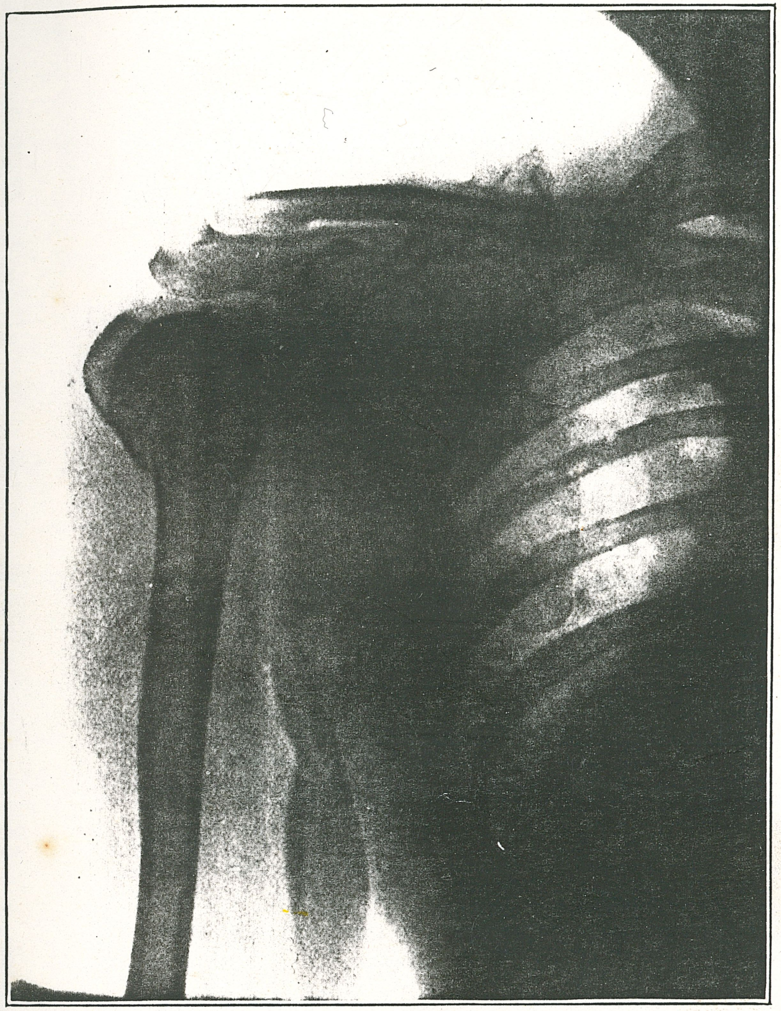

Fracture of surgical neck of humerus, with two fragments split off from the internal and external aspects of the head. Taken with one of the author's coils by Dr. R. W. A. Salmond.

Exposure 14 seconds. 6 Milliamperes.

Frontispiece.

INDUCTION COIL DESIGN

BY

M. A. CODD

WITH 169 ILLUSTRATIONS, INCLUDING 14 PLATES

NEW IMPRESSION

London

E. & F. N. SPON, Ltd., 57 HAYMARKET, S.W. 1.

1922

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LIST OF PLATES

INDUCTION COIL DESIGN.

INTRODUCTION.

The writer, during the many years he has constructed induction coils, has often felt the need of more exact information on points relating both to the theory and practice of this apparatus. Most of the existing books on the subject either view the matter from a purely mathematical standpoint, or else, when purporting to give practical details, omit such essential points that they are useless; both entirely ignore what, for lack of a better definition, we may call "design." Owing to transient conditions the exact measurement of coil phenomena is almost impossible, and it is difficult to give such definite rules as may be laid down for the design of transformers or other electrical machinery, but certain standards can be arbitrarily assigned, however empirical, based on practical experience which is finally the foundation of all formulæ. Many of these standards are missing from the handbooks at present obtainable, presumably because those who have discovered them wish, somewhat naturally, to keep them secret to improve their own manufactures.

In view of the increasing importance of the induction coil in X-ray investigation and in Wireless Telegraphy, as well as in other directions, it is essential that this apparatus should pass from the realm of the philosophical instrument maker into the hands of the

practical electrical engineer, and it is with this object that the writer has, in the following pages, collected data of many of the more generally useful coils he has from time to time constructed, and also such details as are available of other coils for the purposes of comparison and tabulation, and he hopes that these details and the rules for design may prove of help to all interested in induction coils.

M. A. CODD.

CHAPTER I.

THEORETICAL CONSIDERATIONS.

In studying the working of the induction coil its action is too usually considered in the light of ordinary electro-magnetic phenomena, which is, of course, correct to a certain point, but it should be emphasised that the changes taking place also partake of the nature of

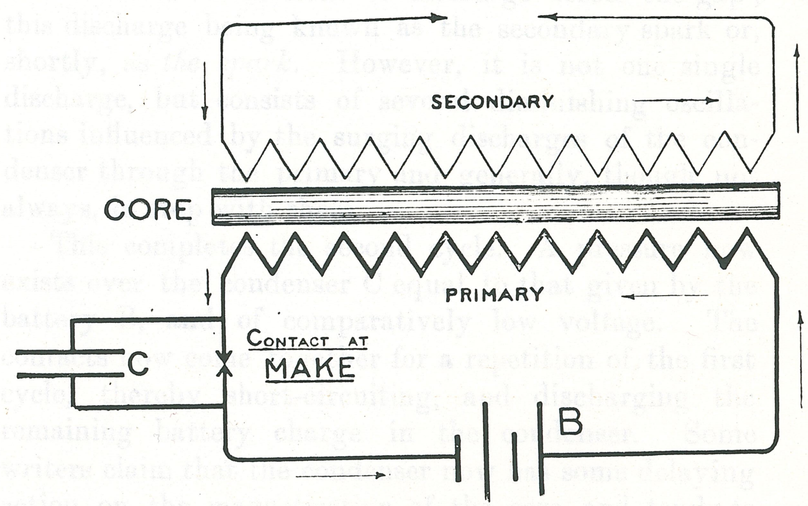


Fig. 1.—Coil circuit closed. Condenser shorted.

high-frequency effects, which factor materially alters the point of view from which the problem must be attacked. For an example in its simplest form we have, in Fig. 1, a circuit consisting of the primary

surrounding its core, directly in series with the battery or source of energy B. Directly the contacts are closed the current begins to flow in the primary, causing a magnetic flux in the core and creating a magnetic field round it. The maximum value of the current is not at once reached owing to the self-induction of the primary, the time taken varying with the voltage employed, as will be subsequently noted in Chapter VIII., Interrupters. Meanwhile the magnetic field, linking more or less perfectly with the secondary

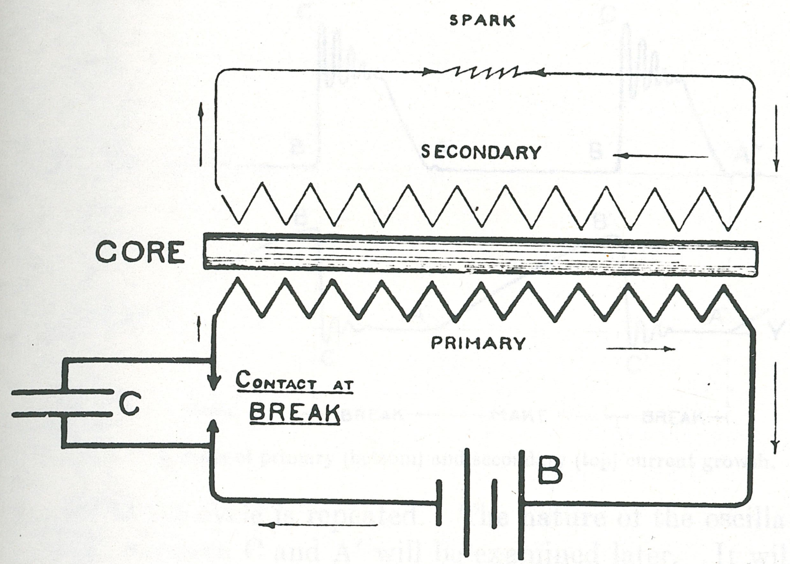


FIG. 2.—Coil circuit open. Condenser oscillating through primary.

coil, has induced in it an E.M.F. which tends to give, or will give, if the spark gap is small enough, a spark of comparatively short length, known as the "inverse current" spark, and for X-ray purposes it is very desirable to reduce this to a minimum. This completes then what may be called the first cycle of operations, the current is at its full value, and the core is fully magnetised. The contacts are now allowed to break (Fig. 2), but as this occurs a spark takes place, which we may

call the primary spark, it being due to the self-induction of the primary and the magnetic energy stored in the core, the current causing the spark being in the opposite direction to that of the magnetising current. It will be noticed that we have now (omitting the battery for the moment) practically an oscillating circuit similar to that employed in wireless telegraphy and the like. The primary spark at the break is not a single flash but the outcome of a series of discharges surging in and out of the condenser C, which is shunted over the discharging contact points, also through the primary, oscillatory in character and rapidly diminishing in value.

Owing to these oscillations there is a rapid collapse of the magnetic lines linking the secondary, which is closely coupled with the primary, and a high potential is induced in it sufficient to discharge across the gap; this discharge being known as the secondary spark or, shortly, as *the spark*. However, it is not one single discharge, but consists of several diminishing oscillations influenced by the surging discharges of the condenser through the primary and generally, though not always, in step with them.

This completes the second cycle. A pressure now exists over the condenser C equal to that given by the battery B, and of comparatively low voltage. The contacts now come together for a repetition of the first cycle, thereby short-circuiting, and discharging the remaining battery charge in the condenser. Some writers claim that the condenser now has some delaying action on the magnetisation of the core, and tends to suppress the inverse current; but it is difficult to see how this can be so, since an uncharged condenser can be connected *after* the circuit is completed, with similar results.

The effects taking place will be more readily followed

by reference to Fig. 3. Here the lines XY represent zero, the lower curve being for primary current and the upper the secondary. Taking first the primary curve, the current is made at A, and grows more or less suddenly (depending on the constitution of the core and primary and the volts applied) till it reaches the point B, at which the interrupter breaks the circuit. From B the current dies away very suddenly, terminating in a few very rapid oscillations between C and A′, at which

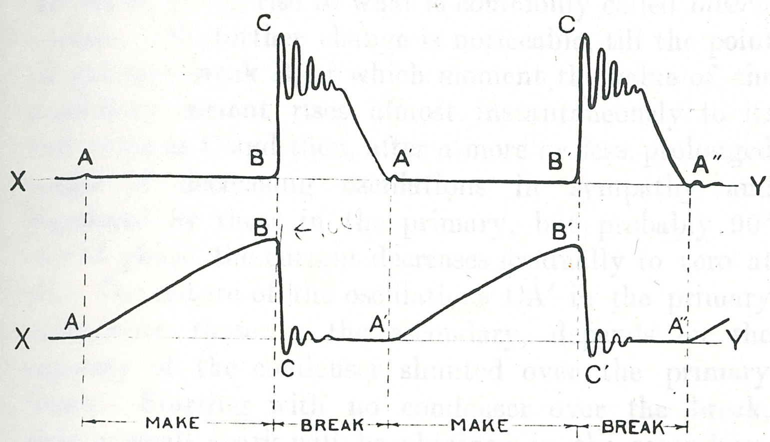


FIG. 3.—Curves of primary (bottom) and secondary (top) current growth.

period the cycle is repeated. The nature of the oscillations between C and A′ will be examined later. It will be noticed that the curve between A and B does not immediately reach its maximum value, but grows slowly, depending on the self-induction and resistance of the primary; the ratio of the self-induction L to the resistance R, is called the *time constant* L/R, and on this depends the form of the curve up to the point, B, of interruption. The speed with which the curve grows depends on the applied voltage V divided by the self-induction, V/L. The total sum of the time of make and break is called the *period* of the interruption, and its reciprocal the *frequency*. It is assumed in this curve

that the point of interruption coincides with the point of maximum magnetisation of the core, the right voltage having been applied to ensure this when the interrupter is running at a known speed. It is obvious, however, that maximum magnetisation might not have taken place at the point B if the coil had a high self-induction compared to the applied voltage, and conversely, the core may have become fully magnetised before the point B, owing to too little self-induction, the remaining part of the curve simply representing wasted energy. To recapitulate: the growth of the curve AB depends on the voltage applied, the time constant L/R, and the maximum value on the rate of interruption of the contact breaker.

Reverting to the second cycle, that is, the period of break BCA′, B represents the point at which the interrupter contacts first separate, and at which the primary spark first appears, and B to C the time during which the current falls to zero, generally something of the order of ·001 second. During the period BC the condenser shunted over the primary spark has become charged, and at C discharges back through the primary and probably through the still existing spark at the break, in diminishing oscillations till equilibrium is restored at the point A′ from point which the cycle is repeated. The nature of the oscillation depends to a great extent on the capacity of the condenser, and the nature of the secondary and its load. A great deal of discussion has taken place as to whether the primary spark occurs only after the geometrical break of the circuit, or not; but if the circuit in Fig. 2 be kept in mind this does not seem difficult to determine. The instant the contacts separate, an arc forms, making a conducting path through the hot vapour caused by the forcible separation of particles of metal constituting the contacts.

When this arc breaks the voltage of self-induction

stored in the condenser discharges, and surges through the primary in decreasing oscillations, thereby demagnetising the core, as already explained.

Referring to Fig. 3, we will now examine the changes that occur in the secondary. Starting at the zero line we see at A a slight ripple due to the closing of the primary circuit. In this case it is a small disturbance hardly noticeable, but, as will be pointed out, it may develop into a most undesirable curve in the negative direction, giving rise to what is commonly called *inverse current.* No further change is noticeable, till the point of primary break B, at which moment the value of the secondary current rises almost instantaneously to its full value at C and then, after a more or less prolonged series of decreasing oscillations in sympathy and regulated by those in the primary, but probably 90° out of phase, the current decreases gradually to zero at A′. The nature of the oscillations CA′ in the primary and hence those in the secondary, depends on the capacity of the condenser shunted over the primary break. Starting with no condenser over the break, only a small spark will be obtained in the secondary, but the addition of even a small capacity considerably increases the spark, which will continue to grow in length with the addition of capacity up to a certain point, after which a further increase of capacity diminishes the length of the spark and also the output of the secondary. This point is generally referred to as the *point of optimum capacity*, and is that in which the nearest approach to resonance occurs between the self-induction of the primary and the capacity of the condenser, having reference to the damping effect of the secondary. This is clearly shown in the curves on p. 9 (Fig. 4), due to Mizuno, from which we see, that for a current of 1·8 ampere, ·1 mfd. is approximately the optimum capacity to obtain a spark length of 1·5

cm., and that either an increase or decrease of capacity results in a decrease in spark length. Further

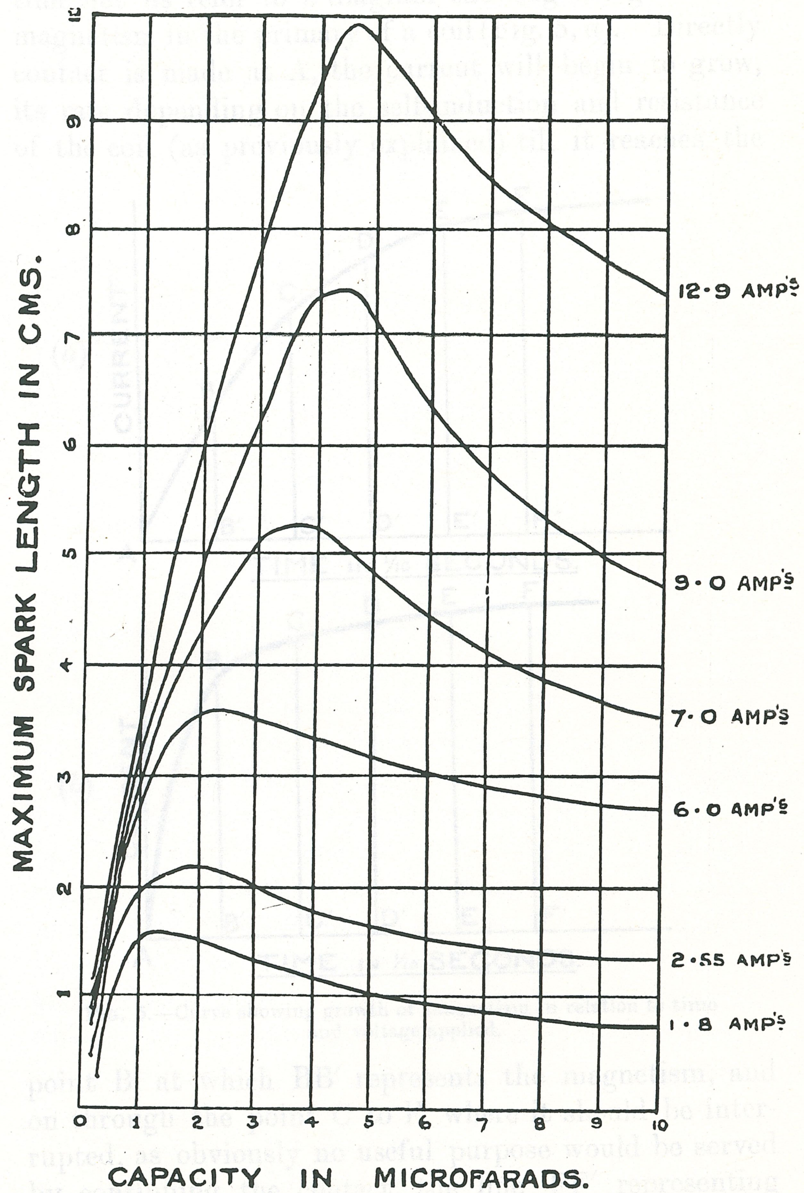


FIG. 4.—Mizuno's curve, showing optimum capacity in relation to spark length and current.

we note that for a current of 12·9 amperes the optimum capacity has to be increased to about ·44 mfd., the best point being increasingly well defined as the current (and spark length) increase. It is noteworthy that these results were apparently obtained with a platinum break, as with a mercury interrupter, the optimum capacity is not nearly so closely defined.

In addition, it should be borne in mind that these results are for *spark length* only, and although a very inadequate condenser will give poor results, a moderate increase in condenser may give a very much greater output when the secondary *current* is in question (see p. 47), hence, most coils for practical work are rather over-condensered; this is particularly true of coils intended for wireless use, in which the secondary load is very heavy.

The damping effect of the secondary has a very important bearing on the oscillations set up between the points CA′ in the primary circuit, and becomes greater as the points of the secondary spark gap are approached till it is a maximum, when the secondary is short-circuited and when it behaves exactly as an "amortisseur."

To obtain the best output from the coil it is essential that the greatest number of complete cycles of make and break should be obtained per second, compatible with complete magnetisation of the core. In Fig. 3 we have roughly $\frac{2}{3}$ of the cycle occupied in make and $\frac{1}{3}$ in break; the ratio of make to break is called the *time economy*.

As probably only a fraction of the duration of the secondary curve is capable of exciting radiations in a cathode tube, it will be seen the greater the number and the longer the duration of these impulses that can be crowded into a second, the higher the efficiency of the coil will be. Now the larger the coil, generally

speaking, the larger is the coil's *periodic time*. Considering the problem from the view of current and time, let us refer to a diagram showing the growth of magnetism in the primary of a coil (Fig. 5, *a*). Directly contact is made at A, the current will begin to grow, its rate depending on the self-induction and resistance of the coil (as previously explained) till it reaches the

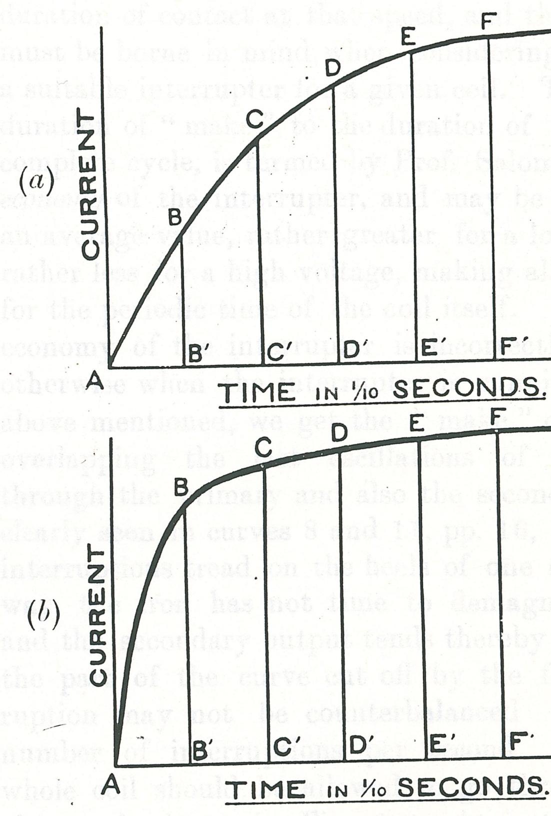


FIG. 5.—Curve showing growth of magnetism in relation to time and voltage applied.

point B, at which BB′ represents the magnetism, and on through the point C to F, where it should be interrupted, as obviously no useful purpose would be served by continuing the contact, the line FF′ representing saturation of the core. The point F is not usually

reached, however, not only because it is in itself wasteful, but for two other reasons: (1) the period taken to traverse the curve ABCD would be unduly wasteful in time, that is the interruptions per second would be too low, (2) full saturation of the core is undesirable owing to the fall of the permeability curve (*q.v.*).

The usual working path is in the region of C and D and the question now arises as to how this degree of magnetism can be obtained the greatest number of times per second. The first suggestion would naturally be to increase the speed of the interrupter, but the effect of this unaided would be to cut down the magnetisation owing to the shorter time of contact, that is, if the magnetisation had previously been CC′ it would drop to BB′, resulting in a greater number of impulses of less magnitude. To obviate this, the self-induction of the coil could be lowered by using fewer turns or less layers of primary, and in effect this is sometimes done in coils having subdivided or removable primaries. The third solution and the easiest, if pressure is obtainable, is to increase the voltage. In this case the curve of growth of magnetisation is more rapid (Fig. 5, *b*), the magnetism, as it were, leaping to its full value in the shorter time necessitated by the increased rate of interruptions.

We have alluded to the working path being in the region of B and C or even D in the curve of magnetisation, but if the interrupter is running too fast, or, when using the Wehnelt break there does not appear to be any evidence that the core entirely loses its magnetisation when working, as, even in the best iron, there is a considerable coercive force, therefore the magnetism probably "floats" from rather over the point A, at minimum, to the points B, C or D, at maximum. This supposition does not for a moment affect the consideration of the primary current or the magnetism, where

the full cycle is accomplished; the current, as we know, falls to zero, and then attains a considerable negative value in the course of its oscillations, thereby causing total demagnetisation of the core.

It will be seen from the foregoing that, with a given coil and a fixed voltage, two factors come into play—the speed of interruption of the current, and the duration of contact at that speed, and these two points must be borne in mind when considering the design of a suitable interrupter for a given coil. The ratio of the duration of "make" to the duration of "break" in one complete cycle, is termed by Prof. Salomonson the *time economy* of the interrupter, and may be taken at ·5 as an average value, rather greater for a low voltage, and rather less for a high voltage, making allowance always for the periodic time of the coil itself. When the time economy of the interrupter is incorrectly designed, or otherwise when the interrupter is running too fast, as above mentioned, we get the "make" of the primary overlapping the last oscillations of the condenser through the primary and also the secondary, as can be clearly seen in curves 8 and 11, pp. 16, 17. When the interruptions tread on the heels of one another in this way, the iron has not time to demagnetise properly, and the secondary output tends thereby to decrease, as the part of the curve cut off by the following interruption may not be counterbalanced by the greater number of interruptions per second. In short, the whole coil should be allowed to go through the complete cycle shown in Fig. 3, to obtain the best results. This is not necessarily true when using X-ray tubes, as we require the peak only, as will be subsequently demonstrated.

At this point it may be advisable to consider the accompanying oscillographs in relation to the conclusions we have arrived at up to the present.

For this purpose a normal 12″ coil was taken with a subdivided primary and condenser.

The oscillograph used was a Duddell Extra High Tension permanent magnet oscillograph furnished with two vibrators, periodic time $\frac{1}{3000}$ sec. The photographs were taken on a plate falling at a known rate of speed, approximately 400 cm. per second. All the secondary results shown were obtained by passing the secondary current through one of the oscillograph vibrators unshunted, the primary current values of course being arrived at by a variable shunt.

The simultaneous results in Figs. 31 to 35 were obtained by earthing the primary and secondary currents respectively through the two vibrators, thereby precluding any risk of breakdown of the oscillograph strips.

The curves when seen on the rotating mirror while the coil is working present very beautiful figures which it is impossible altogether to reproduce, moreover the changing conditions of the spark discharge or the current through a tube can be viewed in a way which renders the various phenomena taking place almost self-explanatory.

Oscillographs were first taken with 1, 2, and 3 layers of primary and with voltages varying from 24 to 240. The results are shown in Figs. 6 to 53, in which the lower curve represents the primary current and the upper the secondary current, in all cases interruption being 50 per second, the primary current 10 amperes, and the gap set at 6″ striking distance. Fig. 6 represents the current produced in the coil, using one layer only on a pressure of 50 volts. Here the growth of the primary current is almost a straight line till the moment of break. A few small oscillations will be noticed at the point of make due to the fundamental capacity of the secondary, as will be shown later.

OSCILLOGRAPHS.

[*Mercury Break.*—All readings at 6″ gap and frequency 50, except where otherwise stated.]

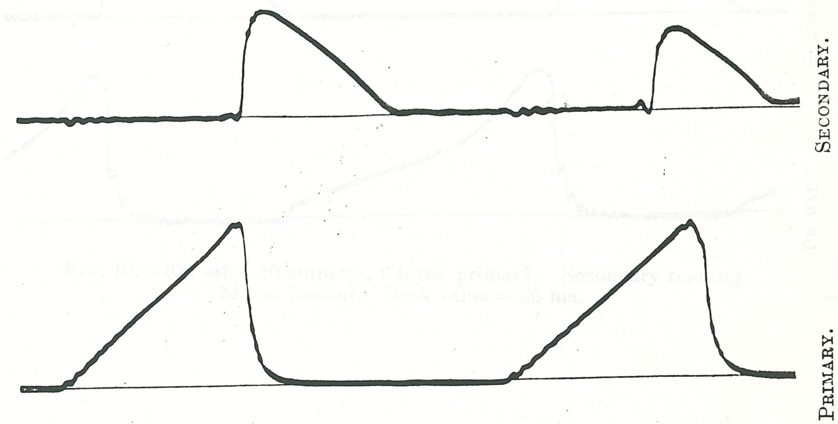


FIG. 6.—50 volts, 10 amperes, 1 layer primary. Secondary reading 7 ma. (mean). Peak value = 45 ma.

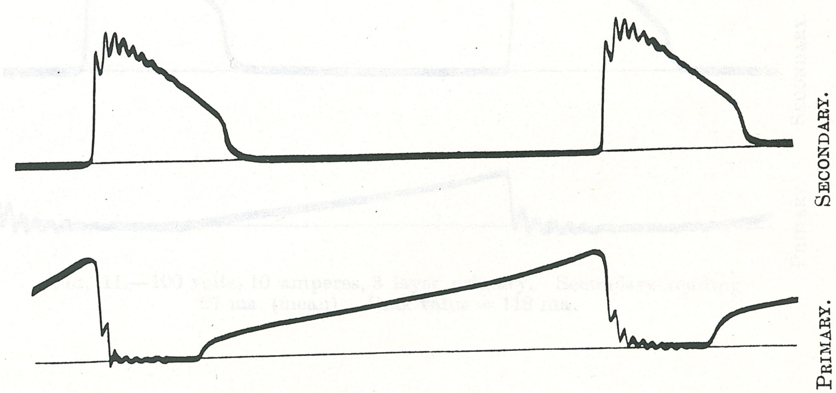


FIG. 7.—50 volts, 10 amperes, 2 layer primary. Secondary reading 14 ma. (mean). Peak value = 77 ma.

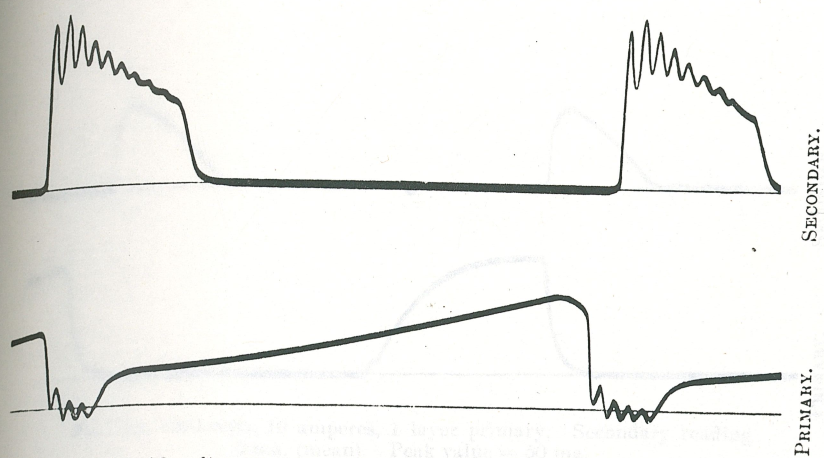


FIG. 8.—50 volts, 10 amperes, 3 layer primary. Secondary reading 14 ma. (mean). Peak value = 100 ma.

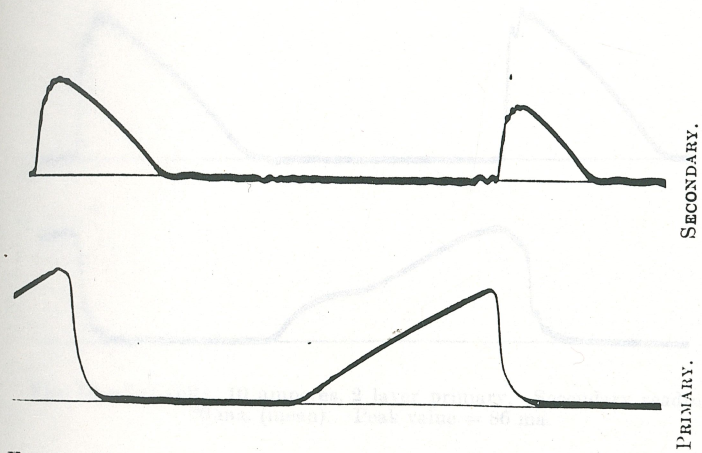


FIG. 9.—75 volts, 10 amperes, 1 layer primary. Secondary reading 11 ma. (mean). Peak value = 60 ma.

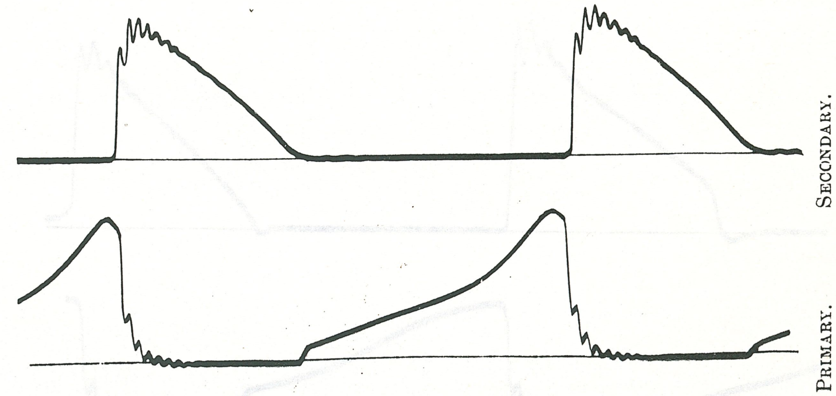


FIG. 10.—100 volts, 10 amperes, 2 layer primary. Secondary reading 22 ma. (mean). Peak value = 80 ma.

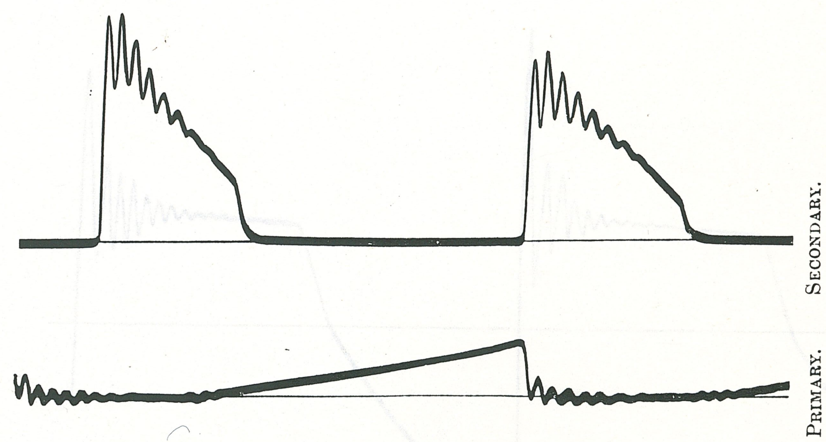


FIG. 11.—100 volts, 10 amperes, 3 layer primary. Secondary reading 27 ma. (mean). Peak value = 118 ma.

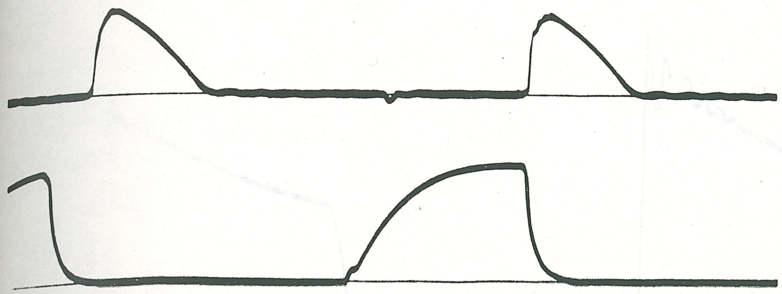


FIG. 12.—240 volts, 10 amperes, 1 layer primary. Secondary reading 5 ma. (mean). Peak value = 50 ma.

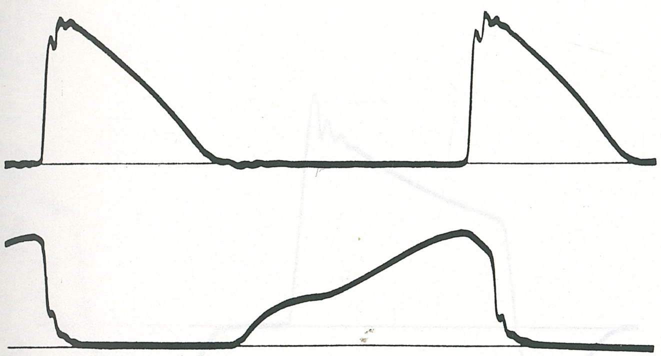


FIG. 13.—240 volts, 10 amperes, 2 layer primary. Secondary reading 20 ma. (mean). Peak value = 86 ma.

FIG. 14.—240 volts, 10 amperes, 3 layer primary. Secondary reading 27 ma. (mean). Peak value = 120 ma.

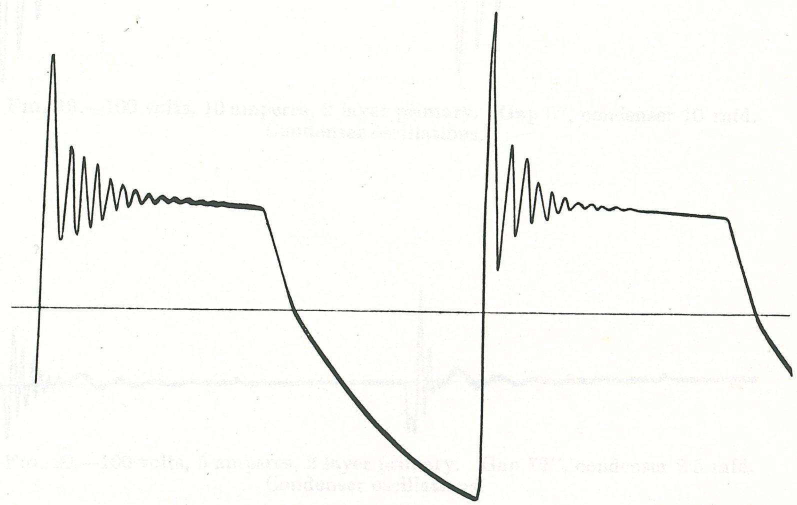


FIG. 15.—50 volts, 10 amperes, 3 layer primary. Gap $\frac{3}{8}''$, showing inverse 0 to 40 ma.

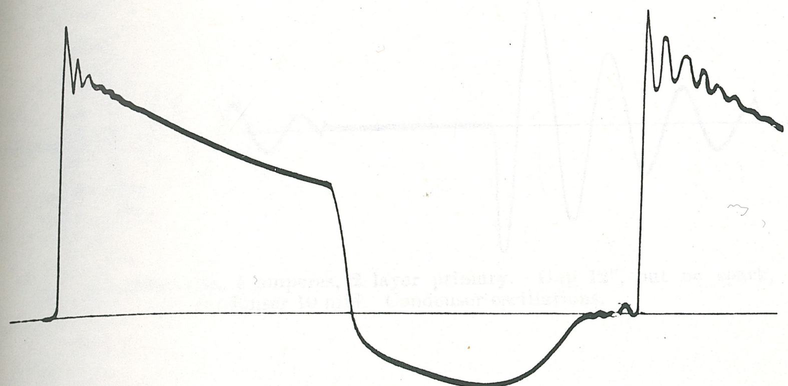


FIG. 16.—100 volts, 10 amperes, 3 layer primary. Gap 2″, showing inverse 60 direct to 40 inverse.

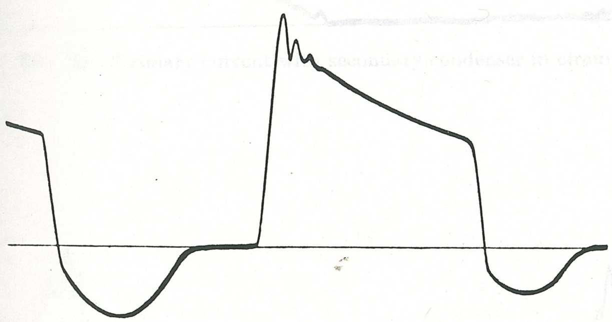


FIG. 17.—240 volts, 10 amperes, 3 layer primary. Gap 3″, showing inverse 35 direct to 35 inverse.

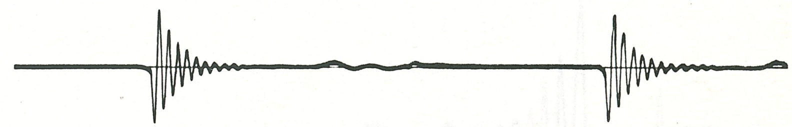


FIG. 18.—100 volts, 10 amperes, 2 layer primary. Gap 6″, condenser 2·5 mfd. Condenser oscillations.

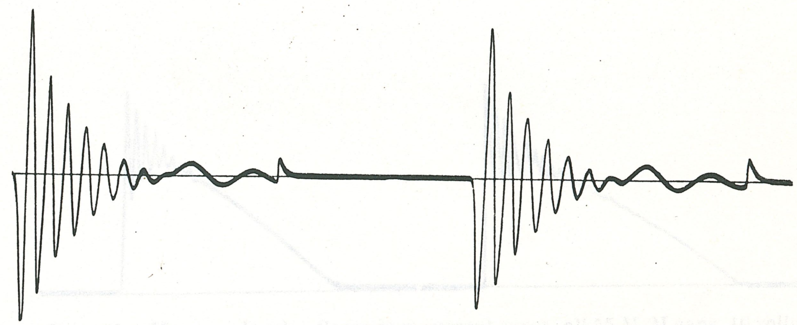


FIG. 19.—100 volts, 10 amperes, 2 layer primary. Gap 6″, condenser 10 mfd. Condenser oscillations.

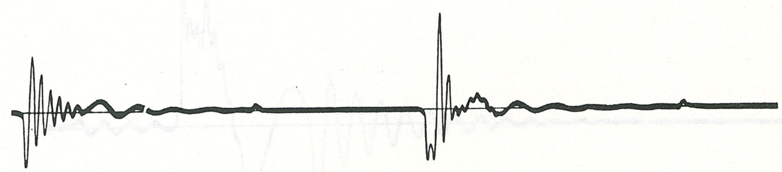


FIG. 20.—100 volts, 5 amperes, 2 layer primary. Gap 12″, condenser 2·5 mfd. Condenser oscillations.

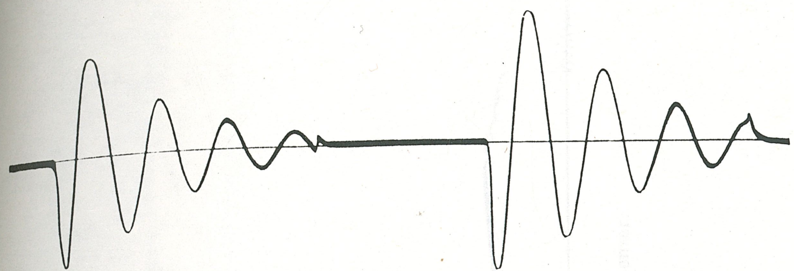


Fig. 21.—100 volts, 5 amperes, 2 layer primary. Gap 12", but no spark, condenser 10 mfd. Condenser oscillations.

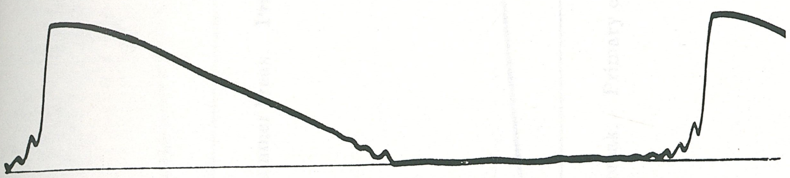


Fig. 22.—Primary current with secondary condenser in circuit.

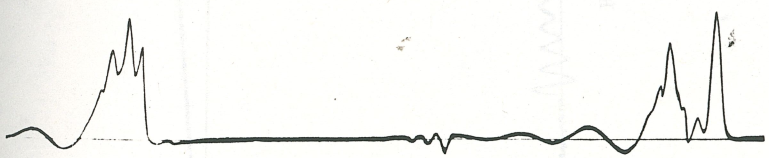


Fig. 23.—Secondary current with secondary condenser in circuit.

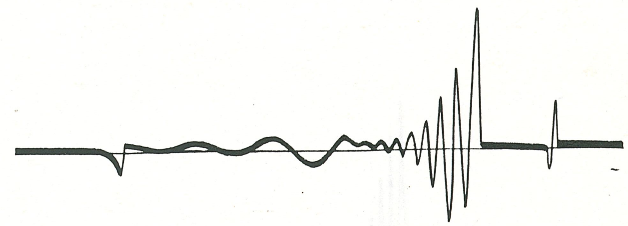


Fig. 24.—Condenser current with secondary condenser in circuit.

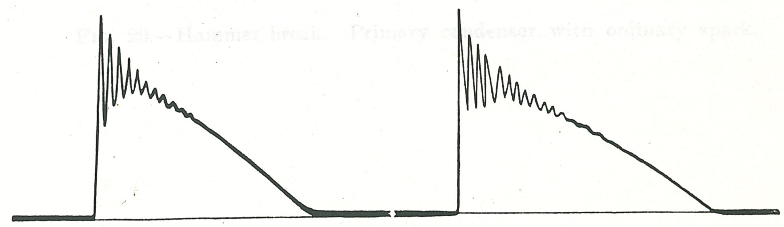


Fig. 25.—Hammer break. Secondary current curve, all 55 M/M gaps, 16 volts, 9 amperes.

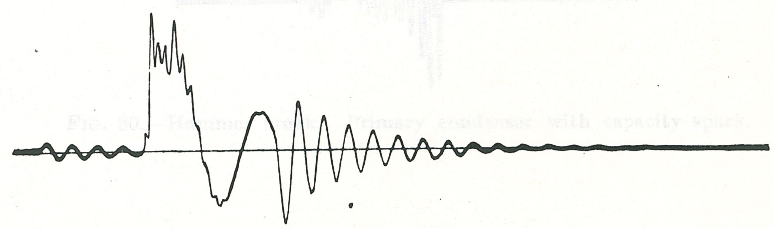


Fig. 26.—Hammer break. Secondary current curve with condenser.

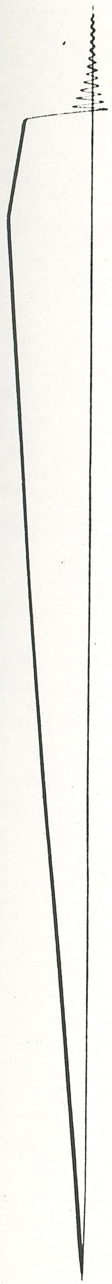


Fig. 27.—Hammer break. Primary current curve.

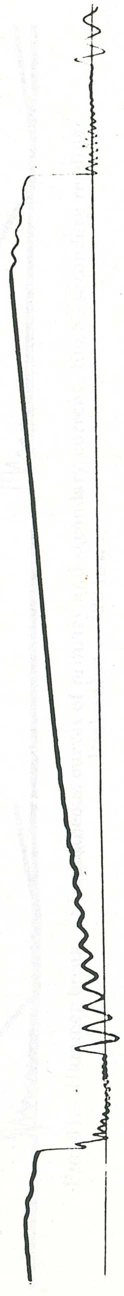


Fig. 28.—Hammer break. Primary current curve with condenser.

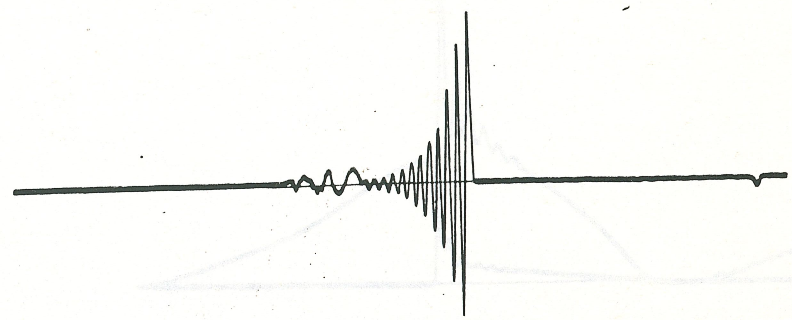


Fig. 29.—Hammer break. Primary condenser with ordinary spark.

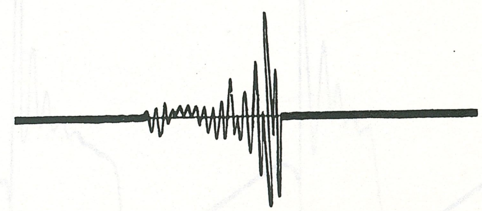


Fig. 30.—Hammer break. Primary condenser with capacity spark.

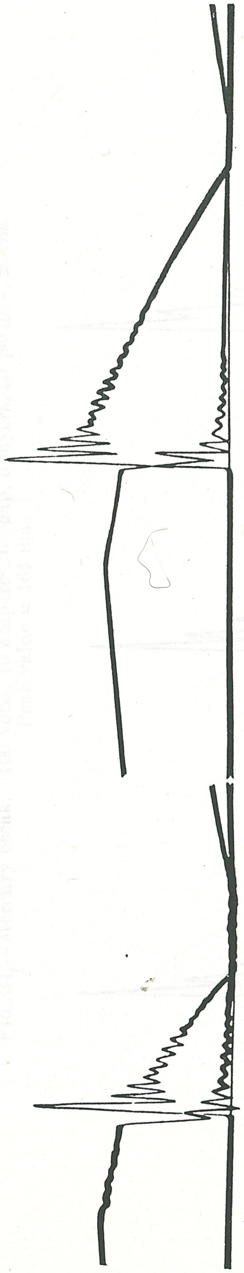


Fig. 31.—Hammer break. Simultaneous curves of primary and secondary current, 10 ma. secondary reading. Peak value = 120 ma.

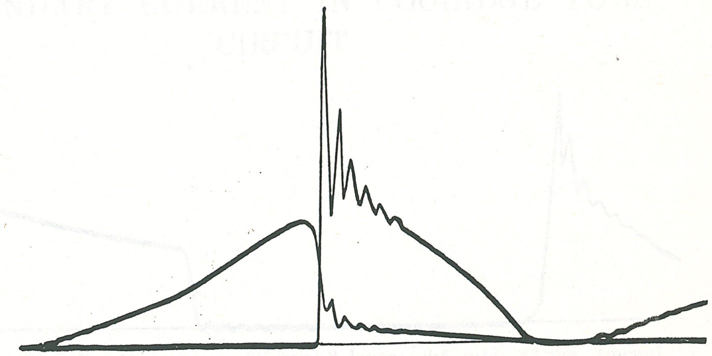


Fig. 32.—Mercury break. 240 volts, 10 amperes, 6″ gap, 3 layers, 50 periods, 25 ma. Peak value = 190 ma.

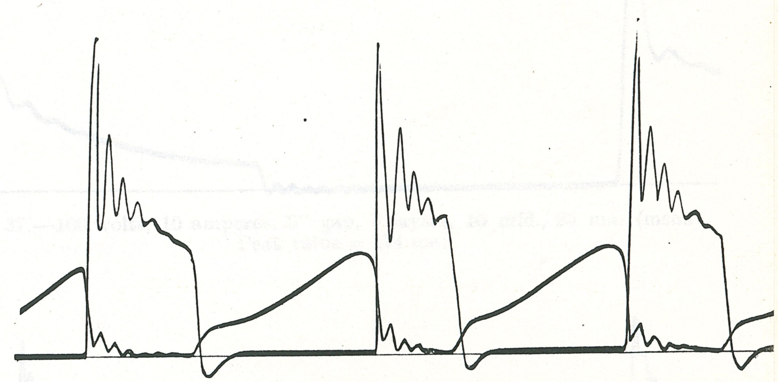


Fig. 33.—Mercury break. 240 volts, 10 amperes, 6″ gap, 3 layers, 88 periods, 35 ma. Peak value = 178 ma.

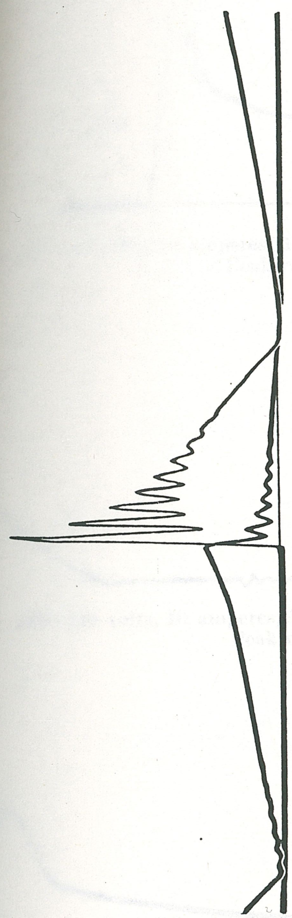


Fig. 34.—Mercury break. 100 volts, 10 amperes, 6″ gap, 3 layers, 50 periods, 20 ma. Peak value = 164 ma.

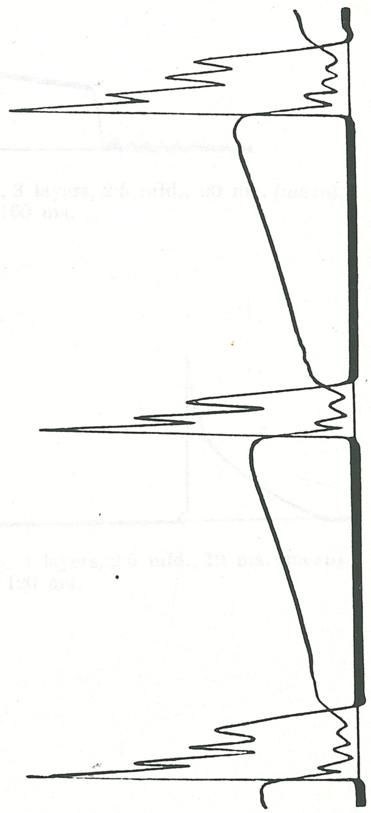


Fig. 35.—Mercury break. 100 volts, 10 amperes, 6″ gap, 3 layers, 88 periods, 25 ma. Peak value = 197 ma.

SECONDARY CURRENT IN COOLIDGE TUBE CIRCUIT.

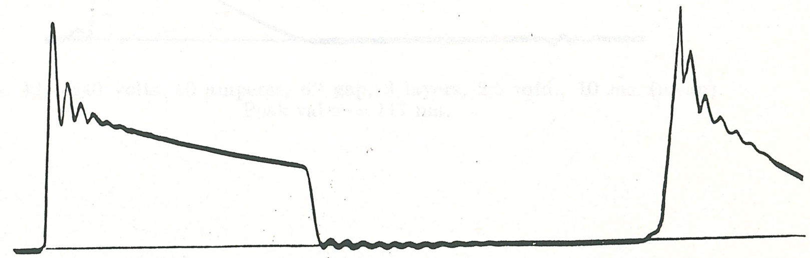


Fig. 36.—100 volts, 10 amperes, 6″ gap, 3 layers, 2·5 mfd., 23 ma. (mean). Peak value = 130 ma.

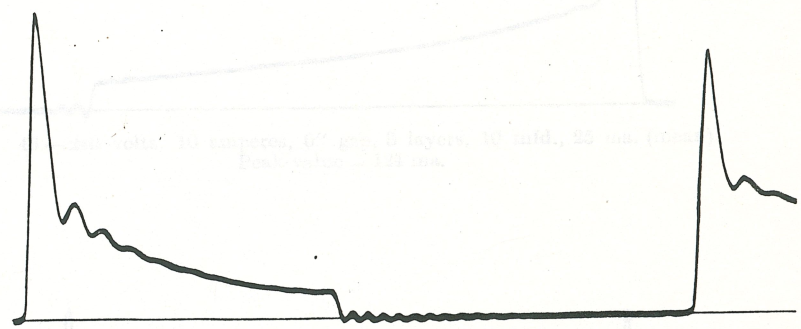


Fig. 37.—100 volts, 10 amperes, 6″ gap, 3 layers, 10 mfd., 25 ma. (mean). Peak value = 174 ma.

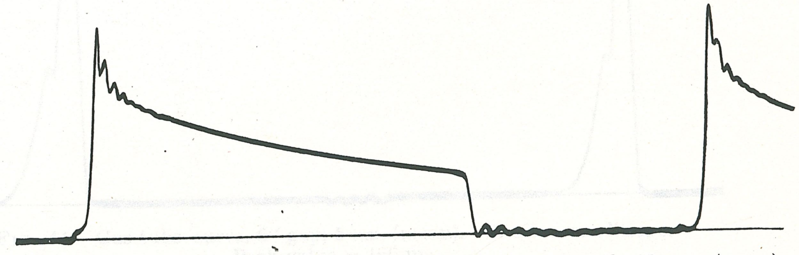


Fig. 38.—100 volts, 10 amperes, 6″ gap, 2 layers, 2·5 mfd., 30 ma. (mean). Peak value = 130 ma.

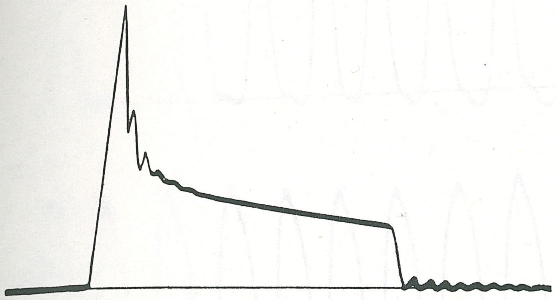


FIG. 39.—100 volts, 10 amperes, 10″ gap, 3 layers, 2·5 mfd., 20 ma. (mean). Peak value = 160 ma.

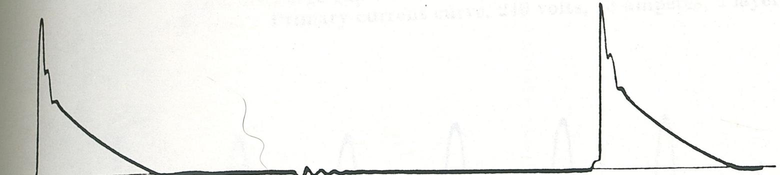


FIG. 40.—240 volts, 10 amperes, 10″ gap, 3 layers, 2·5 mfd., 10 ma. (mean). Peak value = 120 ma.

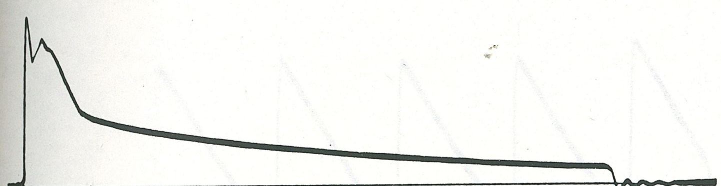


FIG. 41.—240 volts, 10 amperes, 10″ gap, 3 layers, 10 mfd., 15 ma. (mean) Peak value = 100 ma.

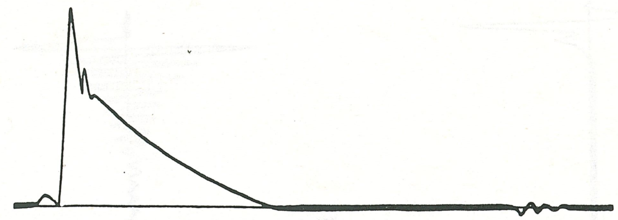


FIG. 42.—240 volts, 10 amperes, 6″ gap, 3 layers, 2·5 mfd., 10 ma. (mean). Peak value = 117 ma.

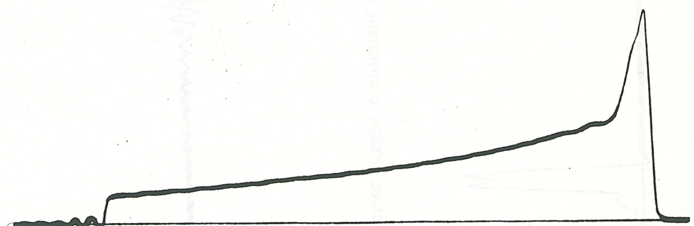


FIG. 43.—240 volts, 10 amperes, 6″ gap, 3 layers, 10 mfd., 25 ma. (mean). Peak value = 124 ma.

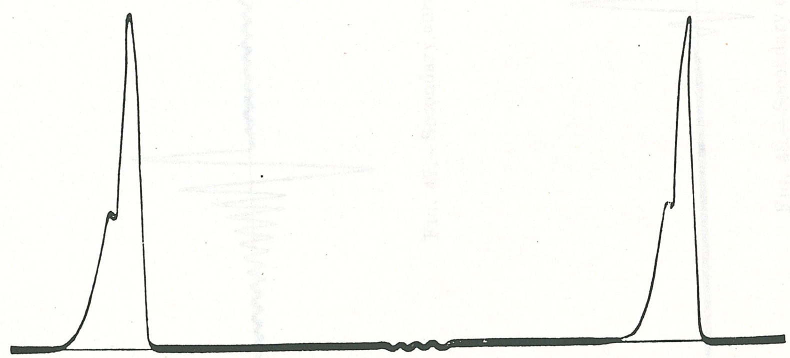


FIG. 44.—Gas tube curve, 6″ gap, 5 ma. (mean). Similar conditions. Peak value = 166 ma.

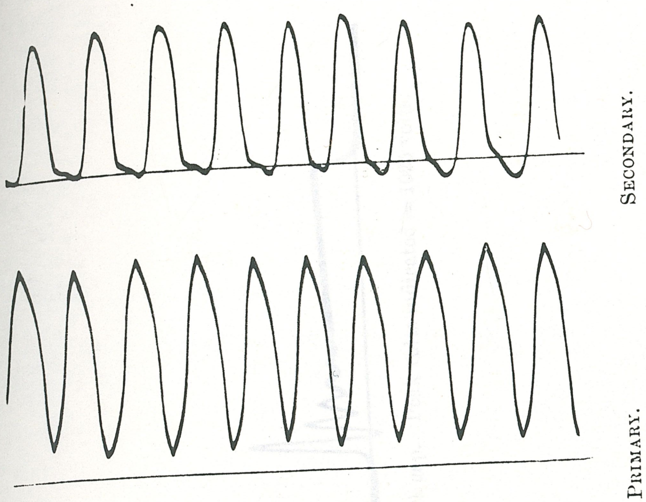


FIG. 45.—Curves of current using Wehnelt break. *Top :* Secondary spark discharge gap 4·25″, 25 ma. Average peak value = 83 ma. *Bottom :* Primary current curve, 240 volts, 13 amperes, 2 layers.

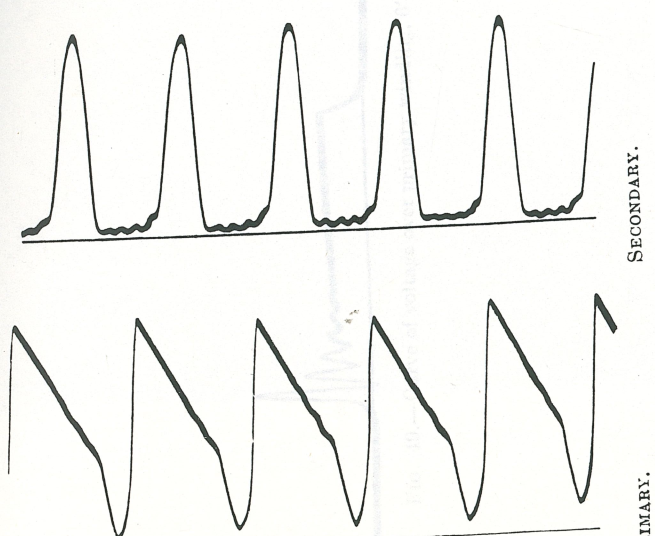


FIG. 46.—Curves of current using Wehnelt break. *Top:* Secondary current through Coolidge tube, 30 ma. Average peak value = 117 ma. *Bottom :* Primary current, 240 volts, 15 amperes, 3 layers.

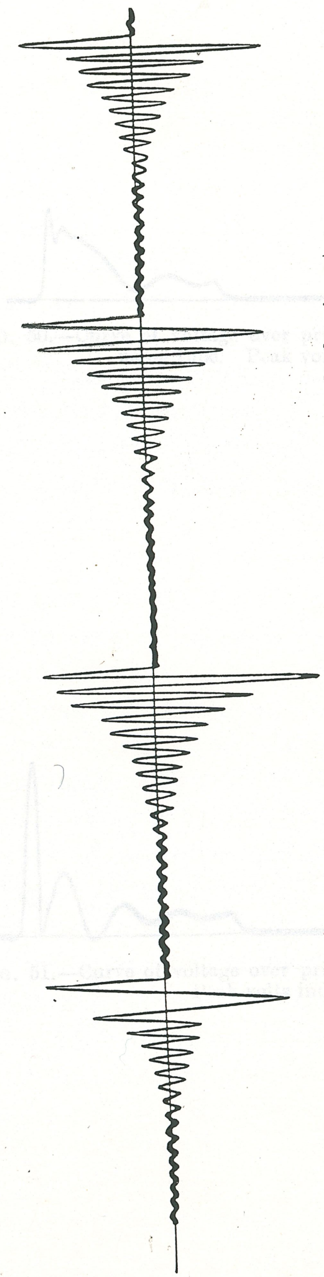


FIG. 47.—Secondary current curve of condenser surges, condenser not discharging at gap.

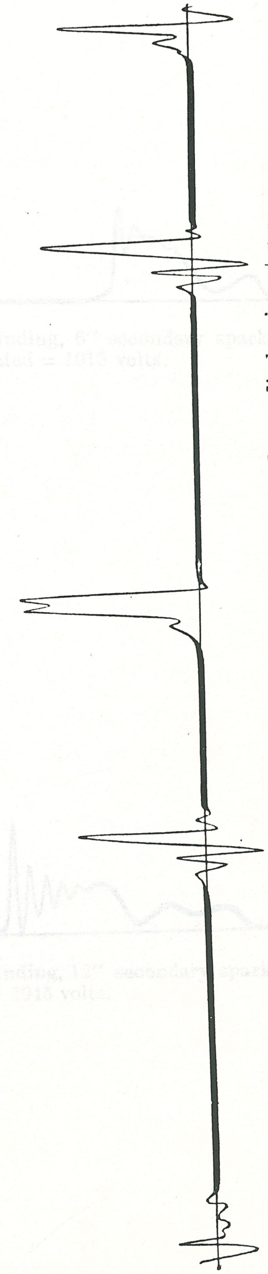


FIG. 48.—Secondary current curve of condenser surges, condenser discharging at gap.

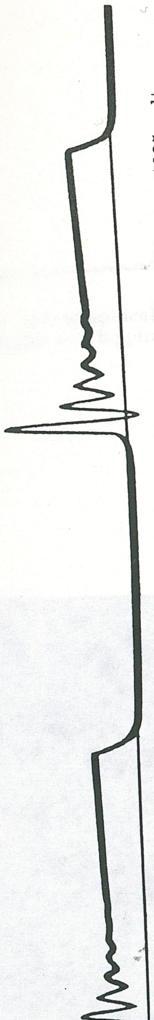


FIG. 49.—Curve of voltage over primary winding, 6″ secondary spark gap. Peak volts indicated = 1025 volts.

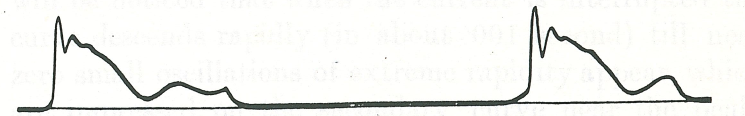


FIG. 50.—Curve of voltage over primary winding, 6″ secondary spark gap, using tube. Peak volts indicated = 1013 volts.

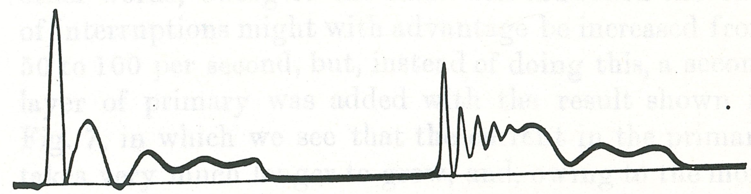


FIG. 51.—Curve of voltage over primary winding, 12″ secondary spark gap. Peak volts indicated = 1945 volts.

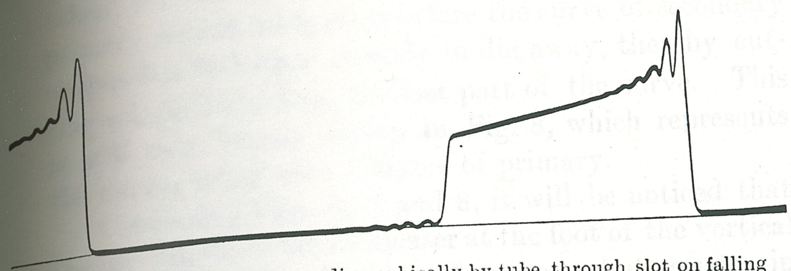


FIG. 52.—Photograph taken radiographically by tube through slot on falling plate, showing double images overlapping in step with first two oscillation peaks of No. 53.

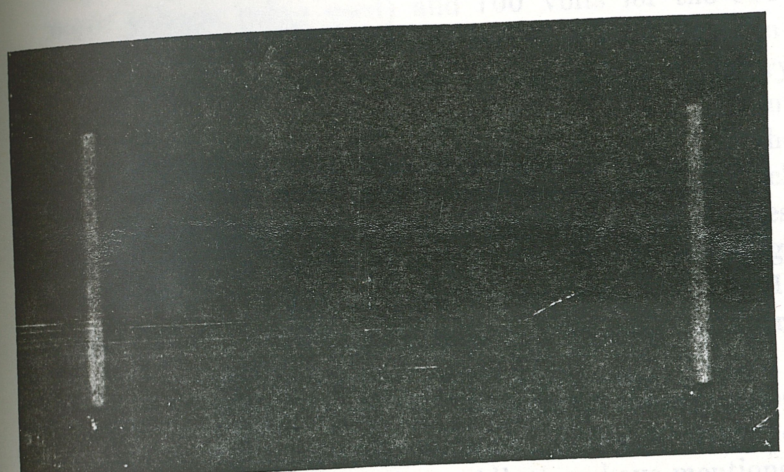


FIG. 53.—Curve of current in Coolidge tube taken simultaneously with No. 52. Peak value = 144 ma.

In the curve of secondary output, just over the point of make, will be noticed a small ripple due to the make in the primary circuit. This ripple under suitable conditions may develop into a complete curve on the negative side of the zero line, forming the inverse current which is so objectionable in radiography. It will be noticed that when the current is interrupted the curve descends rapidly (in about ·001 second) till near zero small oscillations of extreme rapidity appear, which are impressed on the secondary curve near the peak. These oscillations are due to the condenser discharge through the primary at break, and become clearer in the subsequent graphs. The height of the peak of the curve of secondary output corresponds approximately to 45 milliamperes, although the P.M. meter in series read 7 m.a.

It will be noticed that the primary current was still growing at the moment of break, as might be expected with such a comparatively small number of turns, and that therefore there is room for another complete cycle of primary current in between the existing curves. In other words, owing to the small self-induction the rate of interruptions might with advantage be increased from 50 to 100 per second, but, instead of doing this, a second layer of primary was added with the result shown in Fig. 7, in which we see that the current in the primary takes very much longer to grow, and, owing to the more near approach to saturation, the iron shows a distinctly hollow-back curve. This concavity is due to the fact that the iron is not equally permeable, and therefore the self-induction of the coil varies, the permeability becoming less with a stronger current (see curves, Fig. 70). This is very noticeable with higher voltages (Fig. 13) and generally denotes that too much current is being used to magnetise the core economically, or in other words, that the iron is insufficient for the current input.

Another noticeable point is, that owing to the time taken for the magnetism to grow, the make of the primary circuit takes place before the curve of secondary output has had time entirely to die away, thereby cutting off, or truncating, the last part of the curve. This is still more clearly shown in Fig. 8, which represents the curves taken with 3 layers of primary.

Comparing Figs. 6, 7, and 8, it will be noticed that the oscillations of the condenser at the foot of the vertical break line become slower in frequency, but greater in amplitude, as the self-induction of the primary is increased by using more layers, and that these oscillations are impressed in a magnified degree on the secondary curve. This is also true of the six following sets of graphs. Figs. 9, 10, and 11 represent the same curves employing 75 volts (one single layer did not permit of more voltage being used) and 100 volts for the two- and three-layer arrangement respectively. The concavity of the primary current curve in Fig. 10 is very marked, and the straightness of the primary current line in Fig. 11, and the low altitude attained, led the writer to repeat the experiment several times, but each attempt gave the same result. The explanation lies, perhaps, in the steady growth of the current, although it attains no high value, the peak current of Fig. 11 being about 11 amperes compared with the 45 ampere peak value of Fig. 10.

Curves of Figs. 12, 13, and 14 represent the same series of experiments using 240 volts with a steadying resistance of about 3 ohms in series. All the above-mentioned phenomena are present here to a marked degree. It may be remarked that in comparing the single-layer winding, Fig. 12 (240 volts), the current attains a high value very rapidly compared with Figs. 6 and 9, where the growth of the current is almost a straight line. It is rapidly growing curves of this description that tend to create

inverse currents, which, as already pointed out, are so destructive to X-ray cathode tubes, and therefore our aim should be to magnetise the core steadily to a maximum value as in Fig. 11.

It will be observed that in the more strongly marked secondary curves the oscillations impressed on the peak die away before the curve reaches zero value. These peak oscillations probably represent the piercing value of the spark which disrupts the air, and the decreasing straight line represents the arc discharge that follows the spark due to the dying away of the magnetism stored in the iron core. It seems possible that only the actual peak of the curve causes radio-activity in the cathode tube, and therefore the sloping part of the curve is useless for X-ray purposes (see p. 204) though desirable in wireless practice, as will be explained. If this be true, we can see there is no disadvantage in running the interrupter faster to obtain more peak values per second, thereby truncating the comparatively valueless part of the curve, provided always this increase in speed does not admit the possibility of inverse current due to the necessarily quicker magnetisation of the core. Figs. 15, 16, and 17 show the effect of inverse current in the secondary on 50, 100, and 240 volts, the gap being reduced to $\frac{3}{8}''$, $2''$, and $3''$ respectively before inverse current appeared. The addition of extra capacity to the condenser does not apparently reduce the negative wave, its only effect is to augment the size of the wave on both sides of the zero line. It will be noticed that, owing to the heavy current developed, the secondary exercises a strong damping effect, causing the current to be prolonged unduly, hence the truncation of the last part of the direct current curve which has in no case had time to die away entirely. The oscillations in the condenser circuit were next examined. For this 100 volts were

used and two layers of primary, to avoid truncation of the wave form and to allow the full cycle to take place. Graph 18 represents the curve obtained when using the condenser, giving the best general results (2·5 mfd.) with a 6″ gap and using a current of 10 amperes in the primary, at 50 interruptions per second.

It will be seen that the frequency of the oscillations corresponds very closely with those shown at the crest of the secondary wave in Fig. 10. An increase in capacity to 10 mfd. increases the amplitude and the time taken for the oscillations to die away (Fig. 19). The gap was now increased to 12″ and 5 amperes used in the primary in order to lessen the arc-like discharge, the condenser used being 2·5 mfd., the result (Fig. 20) being a number of rapid oscillations similar to Fig. 18, but in the right-hand curve it will be noticed there are a number of parasitic oscillations of extremely high frequency imposed on the main oscillations. These superimposed oscillations are due to the fact that the fundamental capacity of the secondary is beginning to play a certain part in the character of the spark, which is beginning to be a true spark, in contradistinction to the arc or conducting flame, hence we obtain an embyro high-frequency effect, sorted out from the usual arc discharge of the shorter gap. Had the current been increased to make the spark into an arc this effect would have been absent, as it is in the results obtained with the 6″ gap. It is interesting to compare this with the graphs given later (Figs. 24 and 30) for coils when discharging in shunt with external capacities.

Curve 21 shows the result of substituting a capacity of 10 mfd. for the standard of 2·5. In the first place, the coil refused to spark over the 12″ gap with so small a current as 5 amperes, hence the secondary appears to exercise practically no damping effect, and the

condenser current curves are large in amplitude and slow in frequency.

The small ripples between the train of waves in Figs. 18 and 20, and at the end of each set of waves in Figs. 19 and 21, are due to the disturbance set up by the primary "make" which short-circuits the condenser, in the last two cases slightly prematurely, owing to the long drawn out oscillations. The writer, examining graphs of the condenser circuit in respect to inverse current in the secondary, has been unable to trace any phenomena which appear to throw any further light on the subject, all curves being perfectly normal and similar to Figs. 18 and 20, whether inverse was present or not.

Curves 22, 23, and 24 relate to the currents developed in the primary, secondary and condenser, respectively, of a coil whose secondary is shunted by a small capacity so as to obtain a wireless capacity spark; the growth of current in the primary (curve 22) is nearly normal, but the effect of the secondary capacity is noticeable at the moment of make in the form of a few rapidly decreasing ripples. The secondary current (curve 23) shows the characteristic parasitic high-frequency ripples superimposed on the usual secondary wave form. The condenser current (curve 24) is fairly normal (although high-frequency surges can just be detected) owing probably to the exceeding small capacity of the condenser shunted over the secondary which was of the order ·00012 mfd., the gap being 6″. Oscillographs of capacity sparks are very difficult to obtain records of, although the results are quite clear when viewed by the eye.

The following set of curves (Figs. 25 to 30) are on this account interesting, more particularly as the capacity curves are given in comparison with similar curves for ordinary current effects, the coil used being a 10″ with platinum hammer break specially constructed for wireless purposes as an emergency coil for ships' use, in fact

for S O S calls. Curves 25 and 26 show the secondary currents, respectively without and with the use of the secondary condenser (capacity ·0005, 2 jars in series), the gap being ·55 mm. between 2 cm. balls. In curve 25 the superimposed primary oscillations are very clearly seen, but when the secondary capacity is added great irregularities entirely destroy the conventional wave form, the only point clearly discernible being the high-peaked oscillations at "break." Curves 27 and 28 represent the curves of primary current growth, without and with the secondary condenser, and are particularly interesting. Owing to the high self-induction of the primary the current growth is very slow, but increases regularly till it reaches the point at which there is a deflection or "hump." This deflection is due to the geometrical separation of the platinum points which results in an arc, but as yet no primary spark. The platinums continue to separate at increasing velocity till at length the arc gives place to the true primary spark, the condenser is charged and the current interrupted, when the curve falls to zero with subsequent decreasing condenser oscillations. This further goes to prove that the true moment of interruption is not the geometrical break but the moment when the spark first forms at the contacts instead of the arc. Compare this curve now with Fig. 28 in which the secondary is shunted with its condenser. Note first the capacity ripples at the point of make, then the growth of current to the "hump" or deflection, at which point a few waves occur in the arc, due to capacity effects in the secondary which are reflected in curve 26 before the moment of break, then occurs the true interruption followed by the usual condenser oscillations with superimposed high-frequency disturbances. Curves 29 and 30 represent the condenser current curves without and with the secondary condenser respectively, and are given for completeness, as although they do not disclose any novel points they are of interest in comparison with 18, 19, 20, and 24.

Further proof that the moment of interruption synchronises with the primary spark and not with the first geometrical separation of the interrupter contacts is afforded by the oscillographs 31 to 35, in which the primary and secondary current graphs were taken simultaneously on the same plate.

Fig. 31 represents the primary and secondary currents passing in the 10″ hammer break coil already described, and is in effect curve 25 superimposed on curve 27. It will be noticed that the instantaneous rise of secondary current corresponds exactly with the final or spark interruption of the primary and not with the "hump" where the platinums begin to separate geometrically. Figs. 32 and 33 represent the curves of primary and secondary, using an oil-quenched mercury break on 240 volts at a frequency of 50 and 88 respectively, and 34 and 35 the same but using a 100-volt circuit. The synchronisation of the moment of rupture of the primary current with the growth of the secondary curve is very clear, and it is of interest to compare these curves with those taken separately, namely, 32 with 14 and 34 with 11. In passing it will be noticed that the secondary current in 33 shows traces of inverse, due to the extra speed of the interrupter causing a heavy arc across the spark gap, thereby facilitating the growth of the induced current on "make," also the truncation of the secondary curve in 33 and 35 owing to the succeeding "make" following too rapidly for the complete cycle of secondary discharge to take place. Graphs 36 to 43 show various effects obtained when passing current through a Coolidge tube, the current in the primary in every case being 10 amperes. Figs. 36 and 37 represent the secondary current curves using 3 layers of primary with an alternative gap of 6″, voltage of mains 100, Fig. 36

with a condenser of 2·5 mfd., and Fig. 37 with a condenser of 10 mfd. capacity. In this, as in all the following curves, the effect of the larger capacity is to prolong the flat portion of the curve unduly, and this, although it actually reads a higher milliampereage on the meter, probably is less efficient in the production of X-rays, the protracted portion of the curve merely serving to heat up the tube. Fig. 38 shows the curve obtained when using 2 layers only of primary with 2·5 mfd., the improved output being due to the primary being more suitable to the comparatively low voltage (100) used. The milliampereage fell from 30 to 25 when the capacity of the condenser was raised to 10 mfd. Using 3 layers again on 100 volts Fig. 39 shows the curve obtained when the alternative gap is raised to 10″, the milliammeter reading the same (20) for either 2·5 or 10 mfd. condenser. It will be noticed in all the preceding figures that the curves are truncated owing to the prolonged action of the condenser, and for this coil on 100 volts the condenser could have been reduced advantageously. As, however, the coil is now to be used for 240 volts the condenser was retained to avoid a complication in comparisons. Fig. 40 shows the curve of the coil still with a 10″ gap using 3 layers of primary and 2·5 mfd. capacity. The m.a. have fallen to 10, in comparison to 20 with the 100-volt circuit. Truncation has, however, disappeared and the peak value is comparable, hence the speed of interruption could have been increased with advantage. Fig. 41 represents the same conditions using a 10 mfd. condenser. Although the current has risen to 15 m.a., it is doubtful if better radiographic results are obtained from the long flat-topped curve which always appears when the coil is over-condensed. Figs. 42 and 43 represent the same conditions with a 6″ gap using 2·5 mfd. and 10 mfd. respectively.

The short, high-peaked curve of Fig. 42 contrasts strongly with the long drawn out over condensed curve of Fig. 43. Milliammeter readings 10 and 25 m.a. respectively.

Fig. 44 is the graph of the current in an ordinary water-cooled tungsten target tube, mean reading 9 m.a. gap 5″, from which it will be seen the curve is a high-peaked one in contrast to that obtained from a Coolidge tube, which follows, to a certain extent, the curve given by the current in the ordinary arc. This is because the Coolidge tube, being thermionic, has a much lower resistance than the ordinary cathode tube, and therefore conducts more current.

Fig. 45 represents the current in the primary (bottom) and the secondary (top) of the coil working direct on 240 volts with a Wehnelt break, using 2 layers of primary and a spark gap of 4·25″, current in the primary 13 amperes. It will be seen that the primary current value never reaches zero, and the interruptions are comparatively slow, of the order of $\frac{1}{800}$ of a second. This accounts for the fact that most coils will not give their spark length so readily with electrolytic interrupters as with mercury breaks, as it will be seen that one of the conditions for maximum spark length is rapidity of interruption and collapse of the magnetic field (p. 5). The curve of secondary current follows that of the primary closely, but does in effect reach zero, with a trace of inverse current in one or two places. The frequency of interruption is approximately 400 per second. Fig. 46 represents the currents in the primary and secondary in a Coolidge tube under similar conditions, except that 3 layers of primary were used instead of 2, the effect being to reduce the period of interruption to about 200 per second; but the time of break remains about as before.

The peculiar saw-tooth formation of the primary

current curve would appear to be due to some slight capacity effect coming into play when the current has assumed about $\frac{1}{3}$ of its maximum value, hence the small superimposed ripples; this condenser effect is probably due to the fundamental capacity of the secondary. The secondary curve itself shows signs of small capacity ripples when the current approaches zero, somewhat analogous to those shown in Figs. 36 *et seq.*, and may be due to the capacity to earth of the cabinet containing the battery which excites the cathode pastille of the tube. The curve shows no signs of inverse, and, it will be remarked, is wonderfully regular, as indeed are all these curves for electrolytic interrupters.

Figs. 47 and 48 show the current flowing in the secondary when charging a condenser connected, in the first place directly, in the second through a rectifying spark gap.

In 47 the current is seen to be oscillatory, flowing in and out of the condenser without being able to charge it sufficiently to break down the alternative spark gap.

In 48 the current is almost unidirectional, and with the identical gap a continuous stream of sparks was obtained.

The conditions governing the charging of condensers for capacity sparks from coils are rather indefinite. Supposing a gap with shunted condenser requires a pressure of 10,000 volts to break down the gap, it is not sufficient that the coil produces a spark equal to 10,000 volts, probably four times this pressure will be required. This depends on the capacity of the condenser in relation to the size and output of the coil. Reference to any of the preceding curves of secondary wave form will show that the maximum or piercing voltage is largely in excess of the main body of the current curve, and, therefore, it is only the root mean square value that is of use for charging the condenser, no matter what the size of the coil may be. It is, therefore, desirable that the coil should produce the maximum current value compatible with sufficient voltage to pierce the air between the gap points, and to this end the secondaries of coils designed for wireless or spectroscopic use are generally wound with coarser wire than those used for radiographic purposes. The load is heavy and also the condenser is usually large to obtain the maximum area of the current curves, and the coil would otherwise be considered over-condensered for X-ray work.

It should be noticed there are two frequencies with capacity sparks: the frequency of the oscillation trains themselves, which depend on the capacity of secondary condenser, and the inductance of the exterior circuit; and also the frequency of interruption of these trains, which depends on the contact breaker in the primary circuit, in other words we have the spark frequency and the oscillation frequency. In the first example shown the condenser used was too large for the coil when directly connected, that is, the voltage of the coil could not rise sufficiently to pierce the gap, owing to the large capacity of the condenser, whereas in the second, owing to the dissimilarity of the rectifying gap, one impulse of current was trapped in the condenser, and being unable to oscillate back through the secondary owing to the rectifying gap, continued to reside therein until the next discharge from the coil augmenting the original charge in the condenser its voltage was enough to enable the spark to pass at the main gap.

CHAPTER II.

THE SPARK.

The secondary discharge may be divided into two classes, the spark proper, which is obtained when the coil is working at its maximum sparking distance with a moderate current, and the flame, which is obtained when shorter striking distances are used. If we set up a coil to work with the discharger rods at the full distance apart, and then switch on the current (adjusted to the minimum), we first notice a bluish glow or *effleuve*, surrounding the points or angles of the discharger pillars. This discharge is accompanied by a strong smell of ozone, due to the decomposition of the oxygen of the surrounding air. As the current is increased the violet glow increases, thereby ionising the air between the gap, till, at length, if the current be slightly increased, vivid white crackling sparks will begin to pass across the discharger points (Fig. 54). This discharge is the spark proper, in contradistinction to the flame or arc. The white sparks so formed represent the peak of the potential curve generated in the secondary and are of extremely high frequency, as can be proved by forming a loop in a piece of bare wire (Fig. 55) and approaching the ends near one another. Every time the spark discharges at the gap, a small spark may be seen at the gap in the loop. It is these discharges of very high frequency which are most destructive to the coil, particularly as they generally

occur when the discharger rods are nearly at their full limit, *i.e.* when the potential of the coil is at its greatest. An increase of current at this point will cause the spark

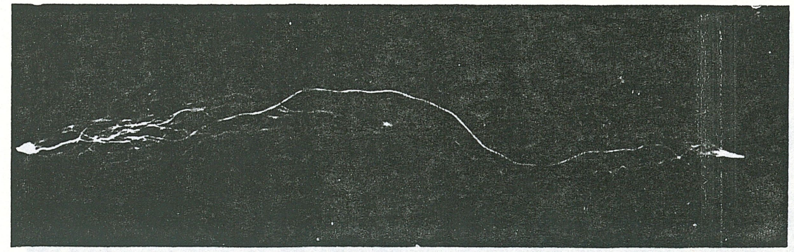


Fig. 54.—Photo of 12″ thin white initial spark discharge.

to thicken successively to a thick violet or chenille-like thread, and then to a whitish flame with a core of white spark giving a loud flapping noise, in which the frequency of the interrupter is discernible, and further increasing

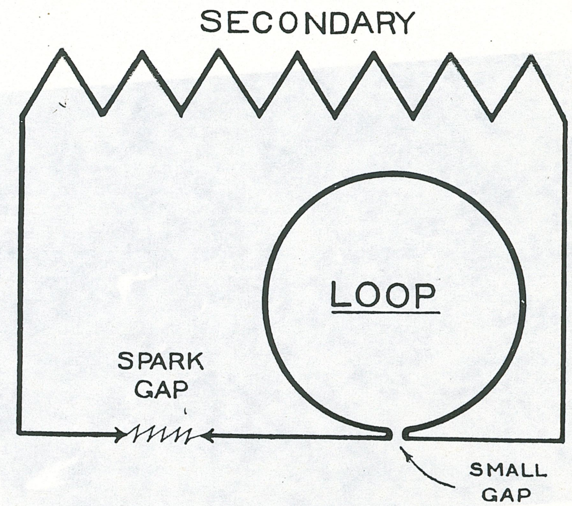
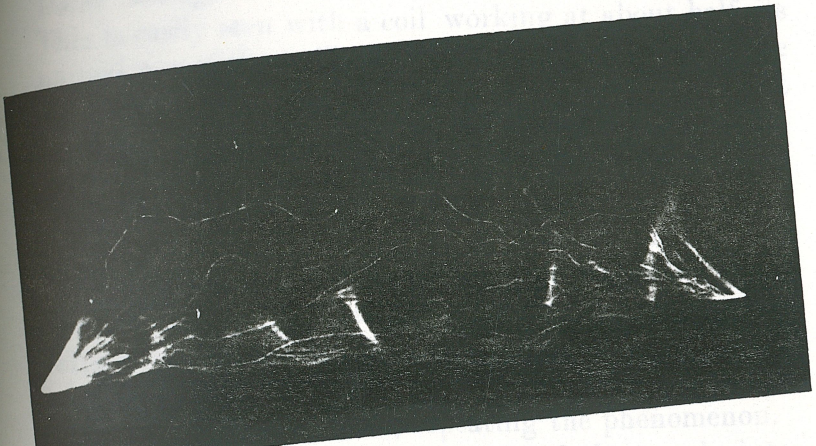
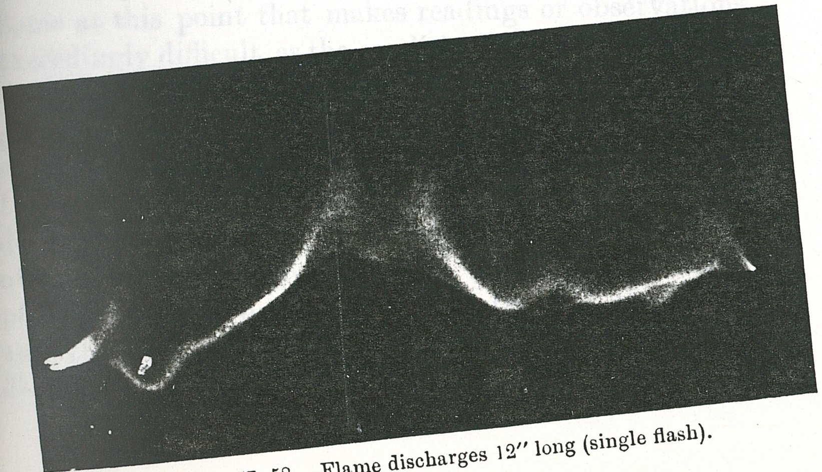


Fig. 55.—Wire loop showing high frequency effect of the current flowing, which prefers to jump the small gap provided to traversing the loop.

the current causes the flame to become very arc-like and almost silent, growing in size as the electrodes are approached one to another.

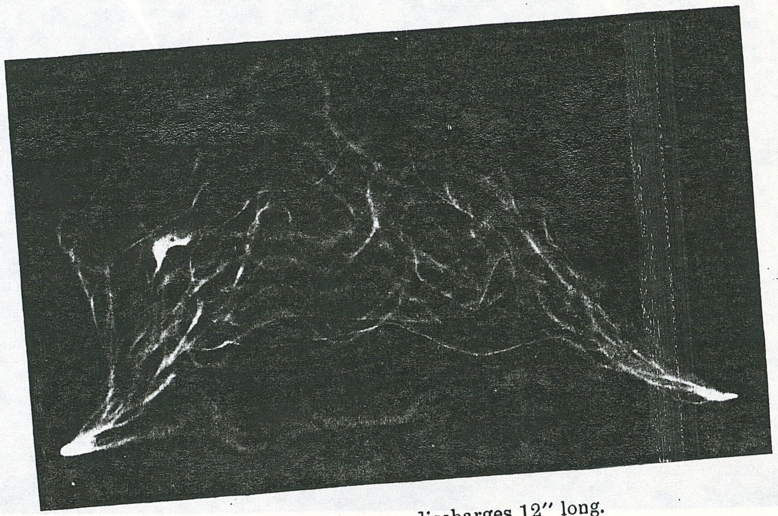
Chenille-like spark.





Figs. 56, 57, 58.—Flame discharges 12″ long (single flash).

Single flash.



Figs. 59, 60.—Flame discharges 12″ long.

The appearance of the flame (Figs. 56 to 60) is doubtless due to the fact that as the electrodes are approached, or the current in the coil increased, the breakdown of the air caused by the first white spark at the peak of the curve is followed by the discharge of the remaining energy stored in the core, and a flame results. This flame forms a tube of hot air or burning nitrogen in the surrounding atmosphere of much lower resistance, through which the succeeding sparks can more readily pass, consequently a conducting path being formed, the striking voltage necessary drops and more current at a lower voltage flows between the discharger points. This is easily seen with a coil working at about half its normal gap with a milliammeter in series. If the flame discharge be blown away the spark discharge is left separated and still passing between the points in approximately a straight line while the milliammeter will fall to less than half its original reading. Indeed, if the spark flame be arranged to take place between horns (Fig. 61) the displacement of hot air will in itself cause the flame to rise to the top, where the gap being too great for the voltage to support it the flame will cease, only to be renewed at the base by the spark passing, and then the flame, which begins to rise, repeating the phenomenon.

It is precisely this splitting up of the spark into flame at this point that makes readings or observations exceedingly difficult, as the conditions of spark and flame, flame and spark, interchange so quickly that it is impossible to take simultaneous readings of various meters and know exactly what was taking place at the gap. Further, it should be borne in mind that the potential difference of the spark is very much greater than that of the flame, because when once the flame has taken place the hot air decreases the resistance of the circuit and therefore the pressure necessary to maintain the discharge. Also the current in the primary will rise

considerably, due to the decreased resistance of the secondary load and the increased secondary current passing in the flame or arc. Moreover, if the gap be

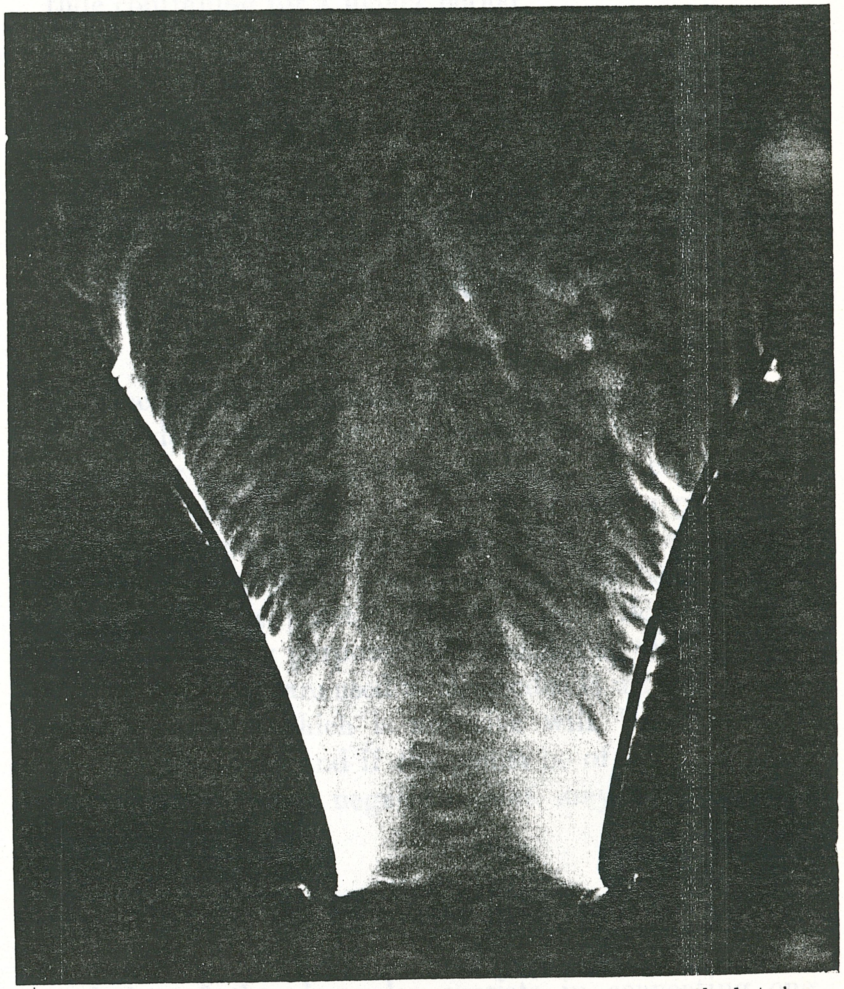


FIG. 61.—Discharge between horns showing displacement of flame by hot air.

rather short and a flame spark is passing we have also, owing to the low resistance of the heated gap, the inverse current due to the "make" in the primary

circuit, and the current in the secondary becomes practically an alternating one with a consequent addition in current value, which still further tends to add to the arc-like nature of the flame. The presence of inverse is easily discernible if a P.M. milliammeter is placed in series with the gap. At the moment inverse current is produced the meter will read lower or drop to zero. In pronounced cases of inverse the meter will swing over to a large negative value comparable with the normal positive reading, at the same time the flapping noise of the discharge will perceptibly change in tone. The long white sparks obtained at full gap are probably not a separate phenomena in themselves, but owe their attenuated vivid characteristics to the fact that the secondary itself is a condenser (p. 133), not only with reference to its own turns and sections, but also due to the proximity of the primary, the tube of which acts not only as an insulator but as a dielectric. That this is so can easily be proved by setting the gap to produce the flame discharge, and then connecting a condenser of small capacity in parallel, when the flame will be replaced by a sheaf of white sparks discharging apparently in parallel. A gap such as this with a condenser in parallel is of course the well-known arrangement used in a wireless circuit, and one of the first points an operator has to avoid is the formation of an arc or flame between the discharger points, else the frequency of the oscillations will fall, and the efficiency of transmission is impaired. Such a spark is generally known as a *condenser* or *capacity spark* (Fig. 62). It should be noted that the bright sheaf of sparks is not one bunch of sparks in parallel, but several, caused by the oscillating discharges of the condenser superimposed on the original discharge of the coil. In the case of the long spark produced by the coil itself the voltage being high and the capacity of the secondary small, we

only obtain one discharge, as the amplitude of the train of waves decreases very rapidly, whereas with a small gap, lower pressure, and an added (external) condenser, we get oscillations of lower frequency and greater amplitude continuing for a longer period.

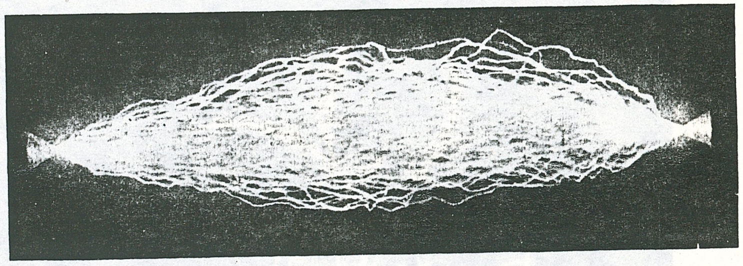


FIG. 62.—Condenser or capacity discharge.

The electrodes between which the spark passes have a well-defined polarity, the easiest way to determine this being to employ a device in which one electrode is furnished with a point and the other with a plate. It will be found that the spark strikes more readily (especially over a fair distance) from the point to the plate when the point is positive, and this electrode should for X-ray purposes be connected to the anode.

If two points are used as electrodes it will be noticed that the point which is negative will become hotter than the positive, and if the points be of small size and the gap short, the negative point may even become white hot.

ELECTROGRAPHS.

Another interesting method of ascertaining the polarity of the electrodes consists in connecting one electrode to a metallic surface, carrying a photographic plate, on which is placed a point connected to the second electrode, the point resting on the film side. A single spark is now allowed to pass and on developing the

plate it will be found that if the point is positive certain well-defined differences occur between the designs as compared with those in which the point is negative. Very beautiful results are obtainable in this way.

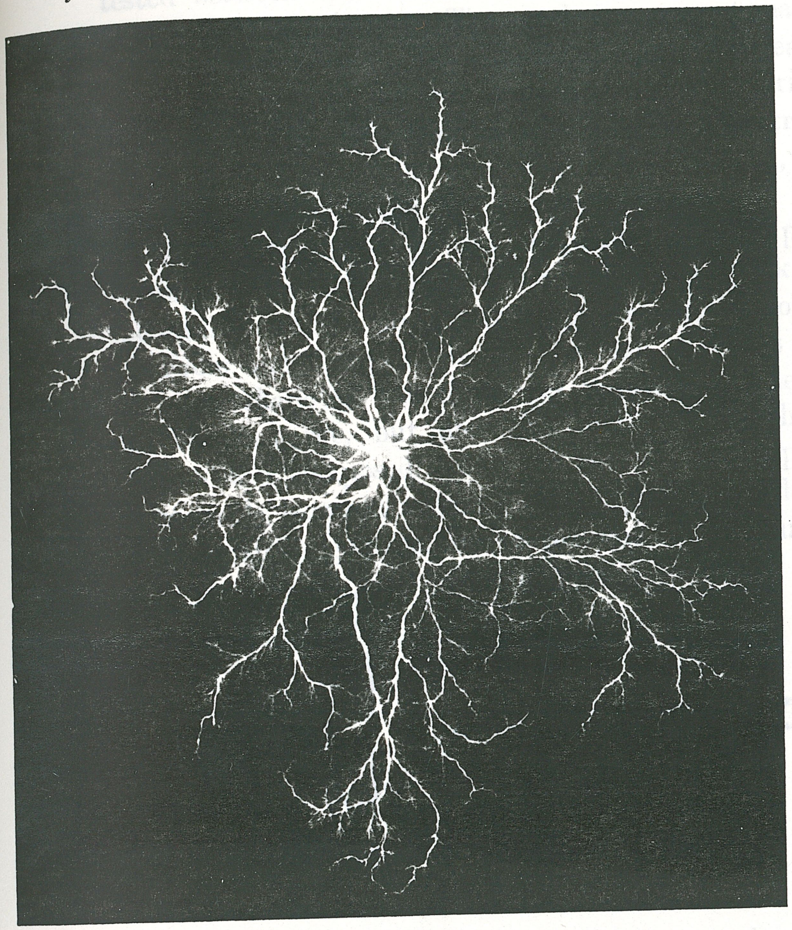


FIG. 63.—Positive electrograph.

Figs. 63 and 64 show results obtained by making the point positive and negative respectively.

When sparks discharge between electrodes, more particularly when the gap is shunted by a condenser, minute particles of the metal of the electrodes are torn

off and pass along the line of discharge. This fact is of the utmost use in spectroscopy, electrodes of various metals being employed in order to obtain the well-known lines on examination, and conversely, certain

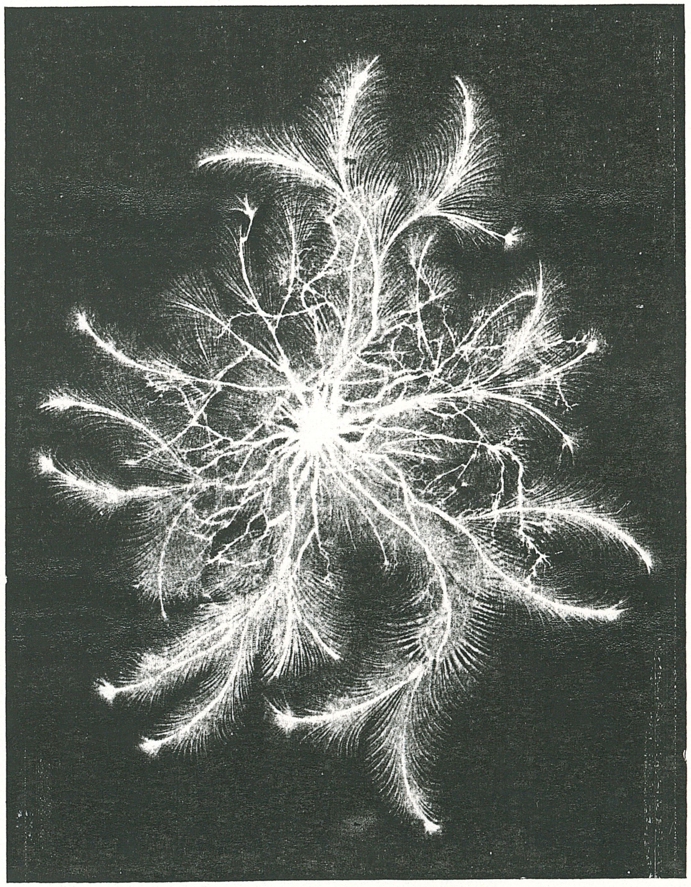


FIG. 64.—Negative electrograph.

lines observed in the spectroscope will determine the nature of the electrodes. In this way by using coins as electrodes it can be determined whether they are of real or spurious metal.

It has already been mentioned that a spark will pass more readily from a point to a plate than from a

plate to a point. It should be remembered that a spark passes still more reluctantly between two spheres, and the full discharge length of a coil should never be tested between balls unless it is known that the coil is intended for this test. The spark passes most readily between two points, and as needle points are easily obtainable this forms the best basis of comparison. Furthermore, sparks pass more readily between electrodes of aluminium than they do between those of zinc, iron and particularly, copper.

Admiralty test gaps are frequently copper plugs having 60° points which, for an ordinary spark, are the equivalent of a gap $\frac{1}{3}$ longer between needle points.

From the foregoing it will be seen that not only does the shape of the electrodes influence the length of the discharge, but also the metal of which the electrodes is composed. The fact that the spark passes more easily between a point and a plate is made use of in the spark gap rectifier to prevent inverse current

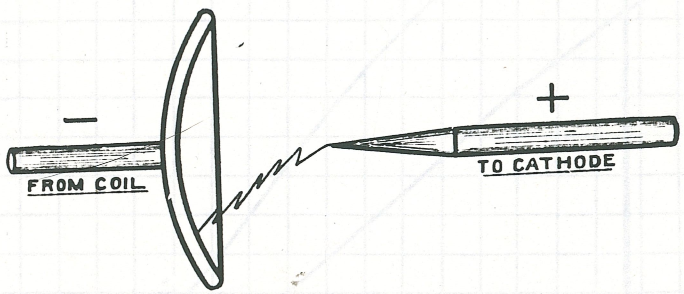
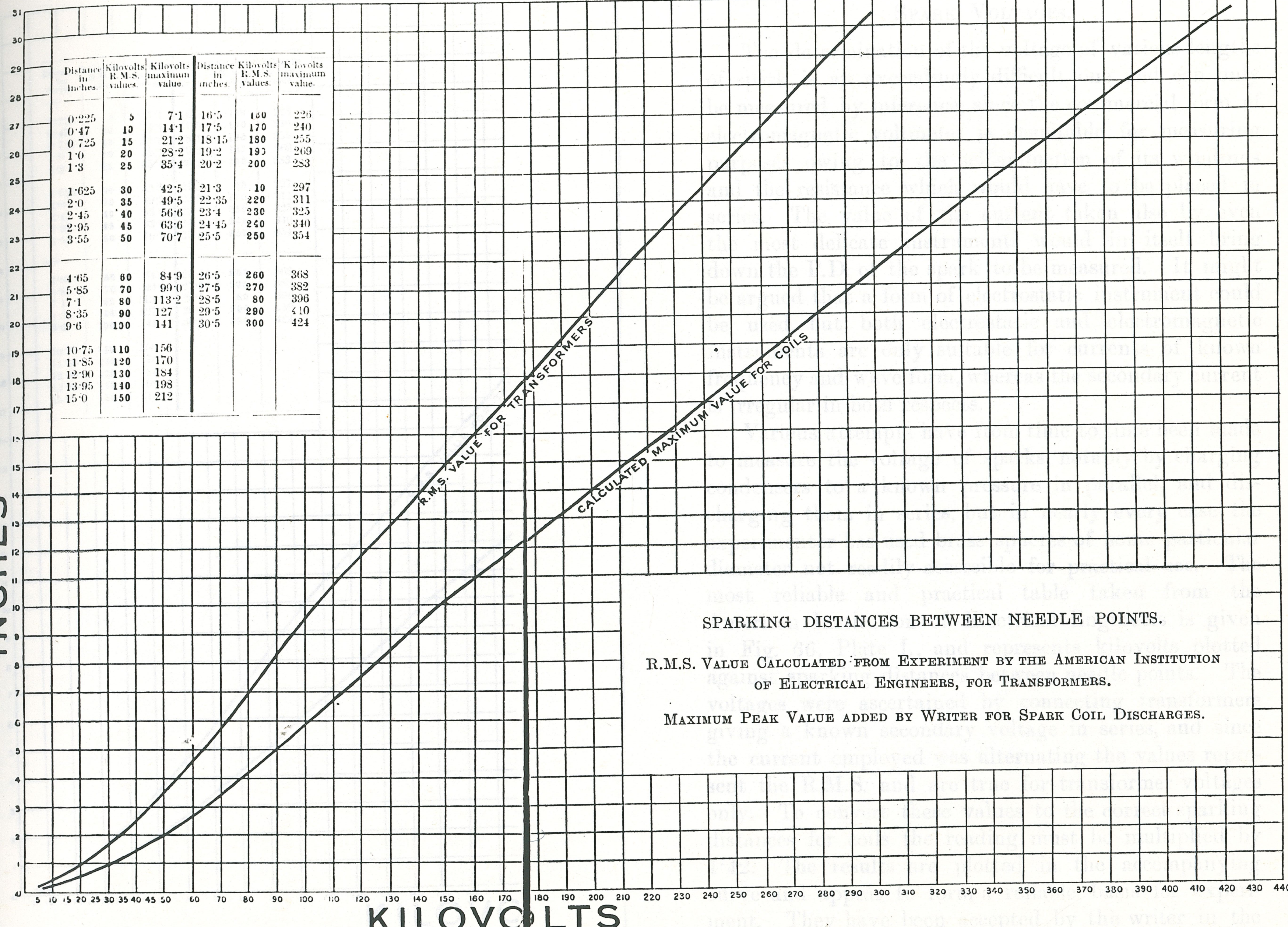


Fig. 65.—Point and cup rectifying gap.

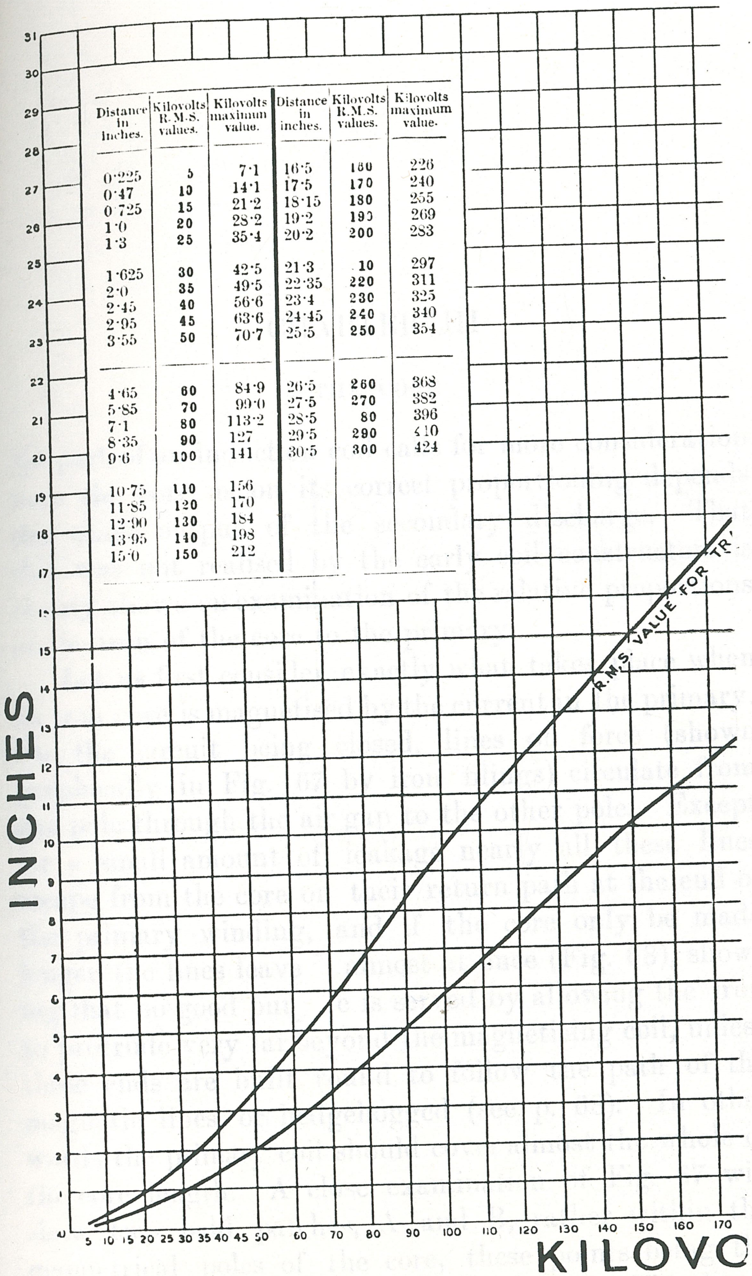
passing through cathode tubes. If the inverse is unduly heavy two or more of these gaps may be used in series.

Duddell has shown that a given gap ceases to rectify a current over a certain value, and that larger current values can be rectified by employing a point and cup than by a point and plate or sphere (Fig. 65).



Distance in Inches.	Kilovolts R.M.S. values.	Kilovolts maximum value.	Distance in inches.	Kilovolts R.M.S. values.	Kilovolts maximum value.
0·225	5	7·1	16·5	160	226
0·47	10	14·1	17·5	170	240
0·725	15	21·2	18·15	180	255
1·0	20	28·2	19·2	190	269
1·3	25	35·4	20·2	200	283
1·625	30	42·5	21·3	10	297
2·0	35	49·5	22·35	220	311
2·45	40	56·6	23·4	230	325
2·95	45	63·6	24·45	240	340
3·55	50	70·7	25·5	250	354
4·65	60	84·9	26·5	260	368
5·85	70	99·0	27·5	270	382
7·1	80	113·2	28·5	80	396
8·35	90	127	29·5	290	410
9·6	100	141	30·5	300	424
10·75	110	156			
11·85	120	170			
12·90	130	184			
13·95	140	198			
15·0	150	212			

To face p. 59. Codd, "Induction Coil Design."] FIG. 66.—Spark length: voltage curve. [*E. & F. N. Spon, Ltd.*



Distance in Inches.	Kilovolts R.M.S. values.	Kilovolts maximum value.	Distance in inches.	Kilovolts R.M.S. values.	Kilovolts maximum value.
0·225	5	7·1	16·5	160	226
0·47	10	14·1	17·5	170	240
0·725	15	21·2	18·15	180	255
1·0	20	28·2	19·2	190	269
1·3	25	35·4	20·2	200	283
1·625	30	42·5	21·3	10	297
2·0	35	49·5	22·35	220	311
2·45	40	56·6	23·4	230	325
2·95	45	63·6	24·45	240	340
3·55	50	70·7	25·5	250	354
4·65	60	84·9	26·5	260	368
5·85	70	99·0	27·5	270	382
7·1	80	113·2	28·5	80	396
8·35	90	127	29·5	290	410
9·6	100	141	30·5	300	424
10·75	110	156			
11·85	120	170			
12·90	130	184			
13·95	140	198			
15·0	150	212			

To face p. 59. Cold, "Induction Coil Design."] FIG.

Spark Voltages.

The determination of the voltage of various lengths of spark is an exceedingly difficult one and can only be measured by inference, since the commercial form of electromagnetic voltmeter is unsuitable for measuring purposes owing to the self-induction of its windings and the resistance which would have to be placed in series. The value of the current taken also by even the most delicate instruments would in itself bring down the P.D. of the spark to be measured. It might be argued that a form of electrostatic instrument could be used, but both electrostatic and electromagnetic instruments are only suitable for currents of known frequency and wave form, whereas the secondary current is irregular in both respects.

Various attempts have from time to time been made to measure the voltage of sparks, notably by charging condensers to a known pressure in parallel, and discharging them in series, but in nearly every case the experimenter has used brass spheres of some particular diameter not readily accessible for practical use. The most reliable and practical table taken from the American Institution of Electrical Engineers is given in Fig. 66, Plate I., and represents kilovolts plotted against sparking distances between needle points. The voltages were ascertained by connecting transformers giving a known secondary voltage in series, and since the current employed was alternating the values represent the R.M.S. and are true for transformer voltages only. To convert these values to the correct sparking distances for coils the reading must be multiplied by 1·42. The results are plotted in the accompanying curve and appear to form a reliable basis for experiment. They have been accepted by the writer in the subsequent estimates of pressure and of output.

CHAPTER III

THE CORE

No part of an induction coil calls for more consideration than the core, as on its correct proportioning depends the whole output of the secondary discharge. That this was not realised by the early coil constructors is clearly shown on examination of the relative proportions of the iron of the core to the primary.

Let us first consider exactly what takes place when an iron core is magnetised by the current in the primary. On the circuit being closed, lines of force (shown graphically in Fig. 67 by iron filings) circulate from one pole through the air gap to the other pole. Except for a small amount of leakage nearly all these lines escape from the core on their return path at the end of the primary winding, and if the core only be made longer the lines leave it almost at once (Fig. 68), showing that no good purpose is served by allowing the iron to protrude very far beyond the magnetising coil, unless these ends are built round to follow the path of the magnetic lines, or hedgehogged (see p. 68). In other words the primary coil should cover almost the whole of the core length. A close examination of Fig. 67 will show two bald patches, A and B, rather within the geometrical poles of the core, these points being the true magnetic N and S poles of the core. This has a considerable bearing on the arrangement of the secondary

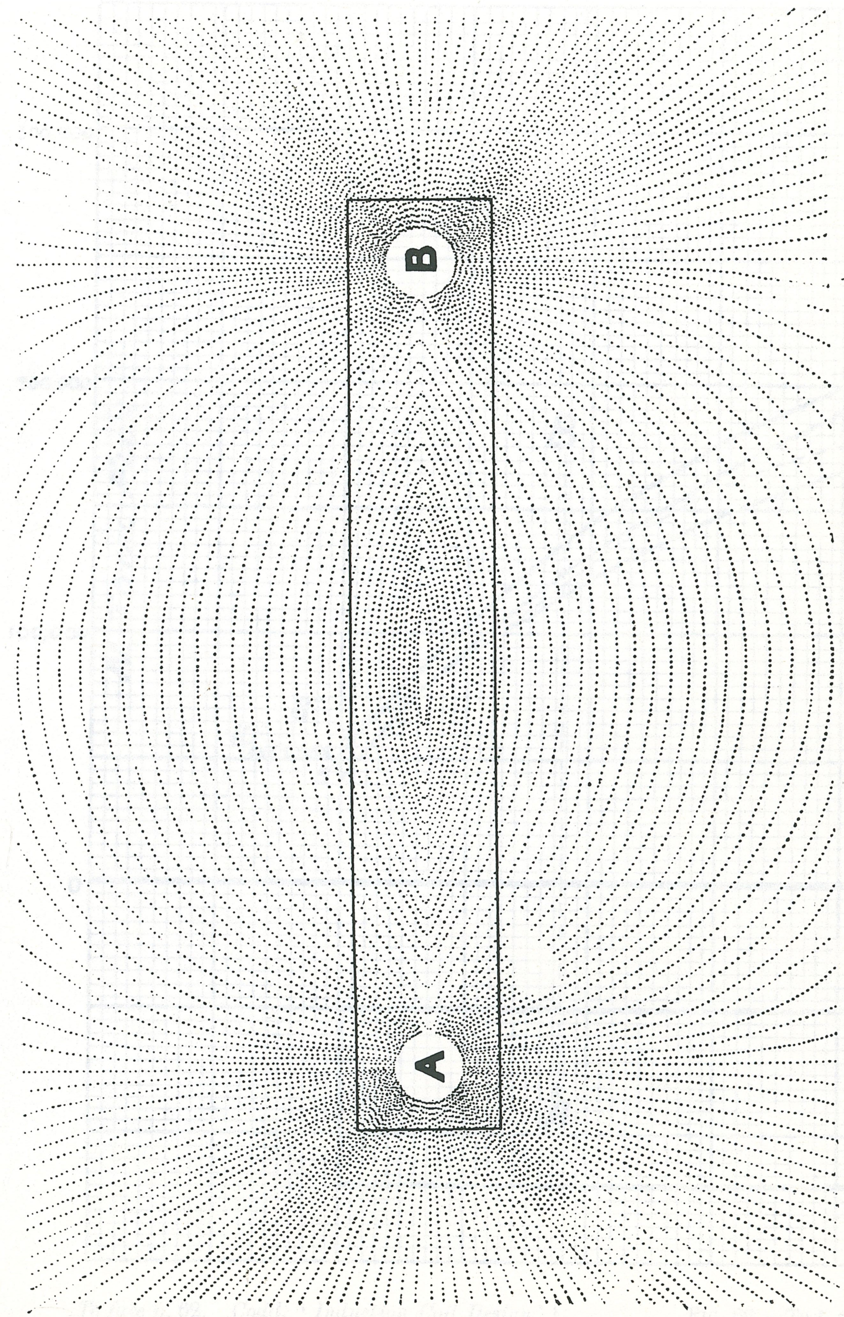


Fig. 67.—Iron filing curve, indicating the lines of force, circulating about the magnetic core.

winding, as the magnetic length of the core is considerably shorter than its real length. Long thin cores have these bald patches A and B much nearer the geometrical poles of the magnet than short thick ones in which the patches move relatively further inward, at a point roughly equal to half the diameter of the core. On this account cores cannot economically be made very short because the magnetic poles within the core become more and more adjacent as the core length diminishes and

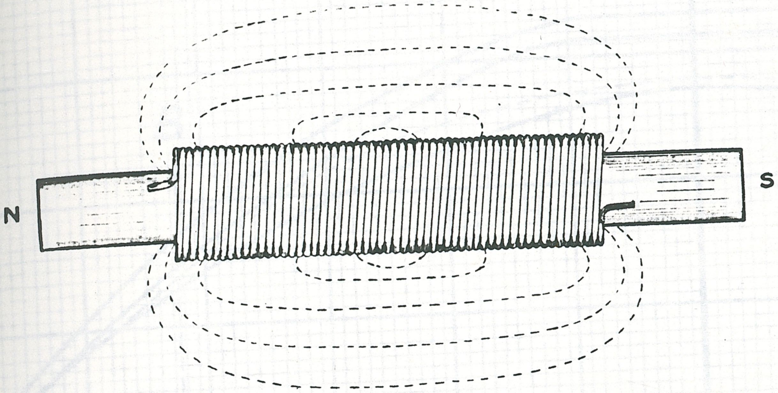
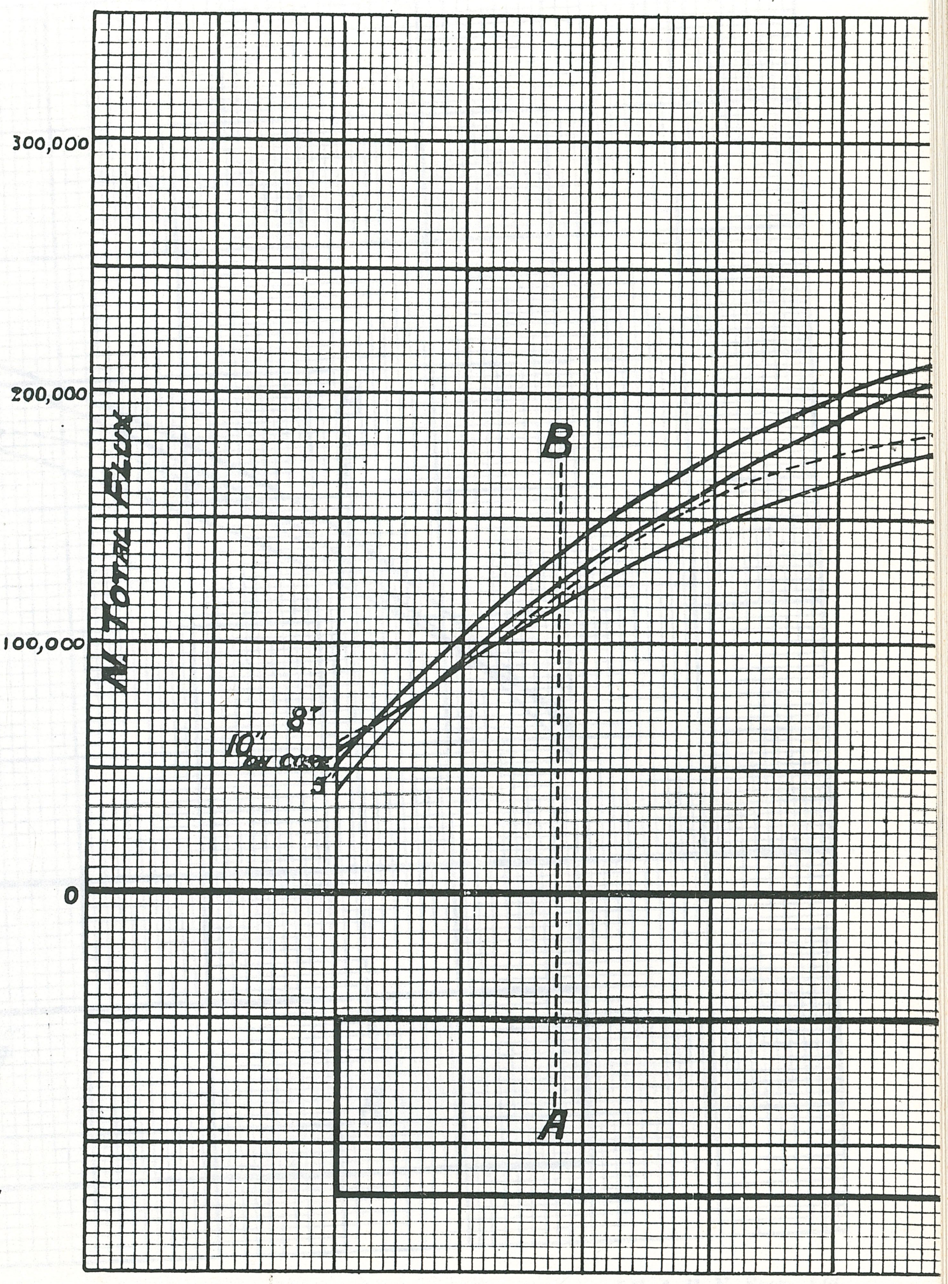


Fig. 68.—Shows leakage of magnetism from core where not overwound with wire.

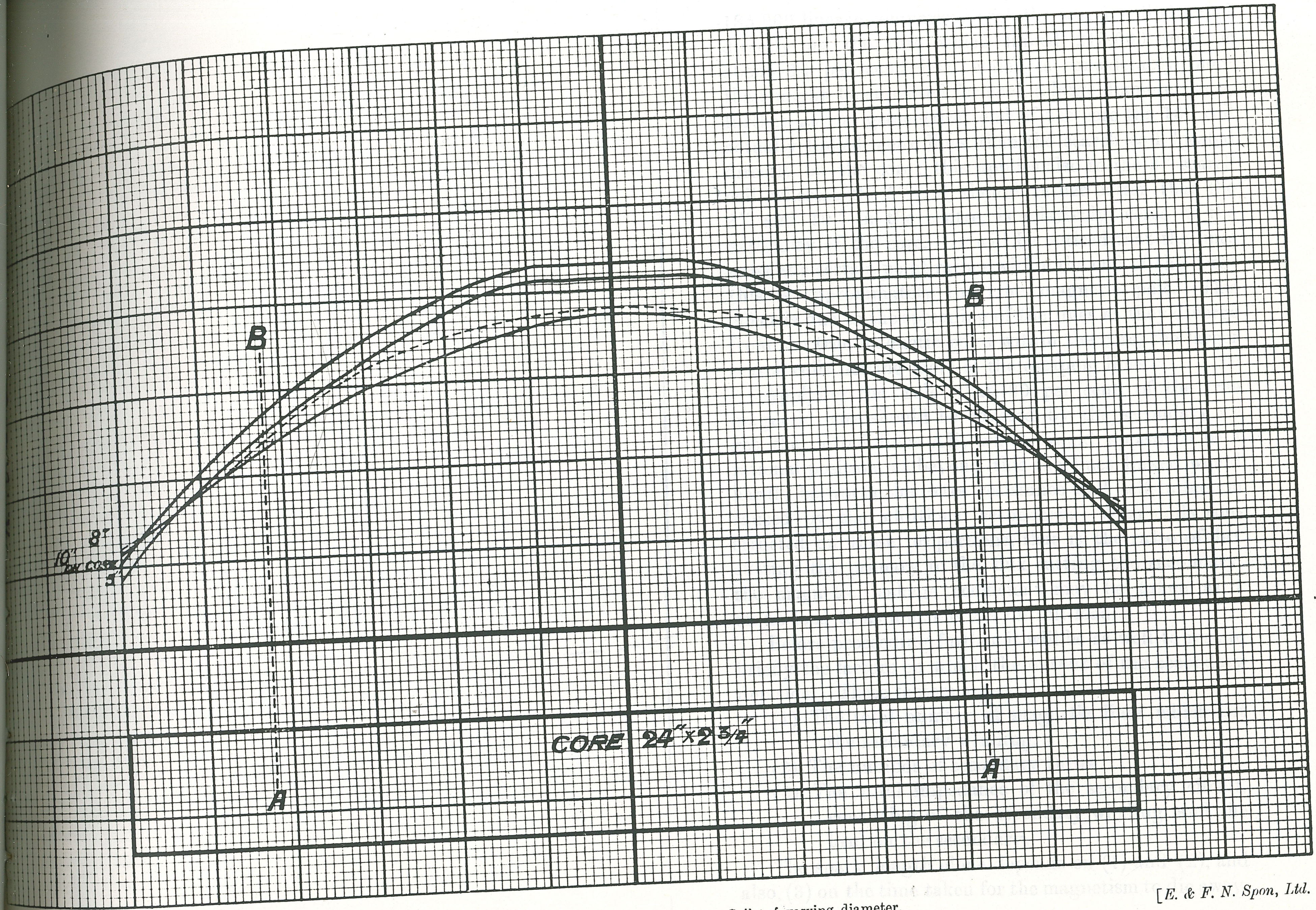
finally begin to demagnetise one another. The best proportion of core length to secondary is attained when the secondary covers 80 per cent. of the magnetic length of the core, the true geometric length of the core being found by adding its diameter. Thus with a core 20″ long and 2″ diameter the true magnetic length would be 18″ and the secondary should cover 80 per cent. of this, namely 14·4″.

Fig. 69 (Plate II.) shows the result of measurements taken with various test coils in positions varying longitudinally on the length of the magnet, the test coils being of increasing diameters; the magnet under examination had a ratio of 8·74. It will be observed that the coil 10″ in diameter at the centre linked



To face p. 62. Codd, 'Induction Coil Design.']

Fig. 69.—Test coil curves



[E. & F. N. Spon, Ltd.

FIG. 69.—Test coil curves along length of magnet. Coils of varying diameter.

185,000 lines in comparison with the search coil situated directly on the core which linked 215,000 lines or about 14 per cent. less, which is considerably more than might be supposed for such a large diameter turn, further at the geometrical end of the core the 10″ coil actually linked *more* lines than the search coil located directly on the core; this applies also to the 8″ search coil, whereas the 5″ coil, though rather better than the 8″ and 10″ in the centre, is relatively worse at the extremity of the core. It will be noticed that the lines cross at a certain point rather within the end of the core; this is approximately the true magnetic pole. This effect is due to the spreading of the lines as they diverge from the true magnetic poles within the core, the larger search coils netting more of the escaping lines.

Applying the rule that 80 per cent. of the true magnetic core should be covered by the secondary we get the dotted lines AB, which would appear to be a rational position, as beyond this the lines linked would hardly be worth the extra resistance and self-induction caused by the additional secondary. With coils constructed on these proportions, that is, the ratio of flux cutting the primary to the flux cutting the secondary, the magnetic leakage coefficient may be taken as 1 on no load to as much as 2·5 on full load.

Before proceeding further it will be as well to restate briefly the factors on which the output of the secondary depends. These factors are—

(1) The total number of magnetic lines which cut the secondary winding.

(2) The number of secondary turns.

(3) The total impedance of the secondary circuit, consisting of the secondary winding and the load on the secondary.

The spark length alone depends on (1) and (2), and also, (3) on the time taken for the magnetism to die away.

From the foregoing it is obvious that the core must be as large as possible compatible with the size and weight at our disposal, and the question arises as to how the iron should be proportioned, in other—words having so many pounds of iron to use, should the core be long and thin or short and thick?

A large number of cores, varying from a few inches to some feet in length, were tested, and the flux density, B, in lines per □″ produced, was plotted against the magnetising force in ampere turns per inch. Fig. 70 (Plate III.) shows some typical examples, the flux density per □″ being plotted against the ampere turns per inch length of core. From this we see that in example A the iron becomes practically saturated at 180 A.T. per inch, giving a flux density of 80,000 lines per □″, and that it is not economical to push the magnetising force further, as an increase of 120 A.T. per inch only results in an increase of 10,000 lines per □″. Curve E, on the other hand, shows no signs of saturation till the point indicated by 950 A.T. per inch is reached, but whereas 200 A.T. per inch in E produces 14,000 lines, in A it produces 82,000 lines per square inch.

It will, therefore, be seen that for a given number of ampere turns per inch a considerably greater flux per □″ is generated when the ratio of L/D is large than when it is small, that is, the longer core can be more economically magnetised than the shorter one.

A curve was now prepared to show the effect of the varying ratio L/D, this ratio being plotted against $\frac{\text{flux density}}{\text{A.T. per inch}}$ the result being practically a straight line (Fig. 71, Plate IV.). This shows that a very much greater flux density is produced for a given number of ampere turns per inch when the ratio is large, in other words the longer the core the more economically it can

PLATE III.

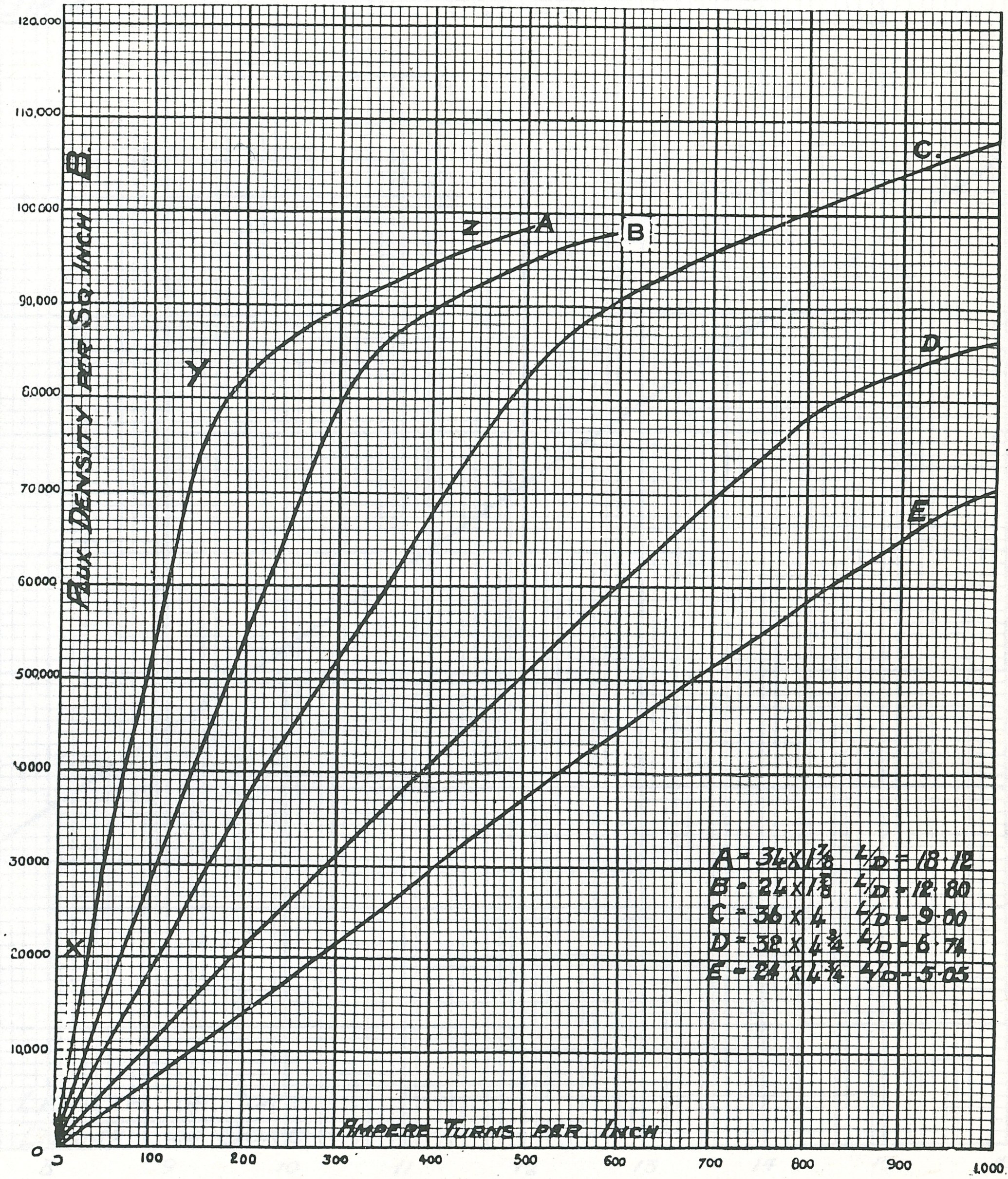
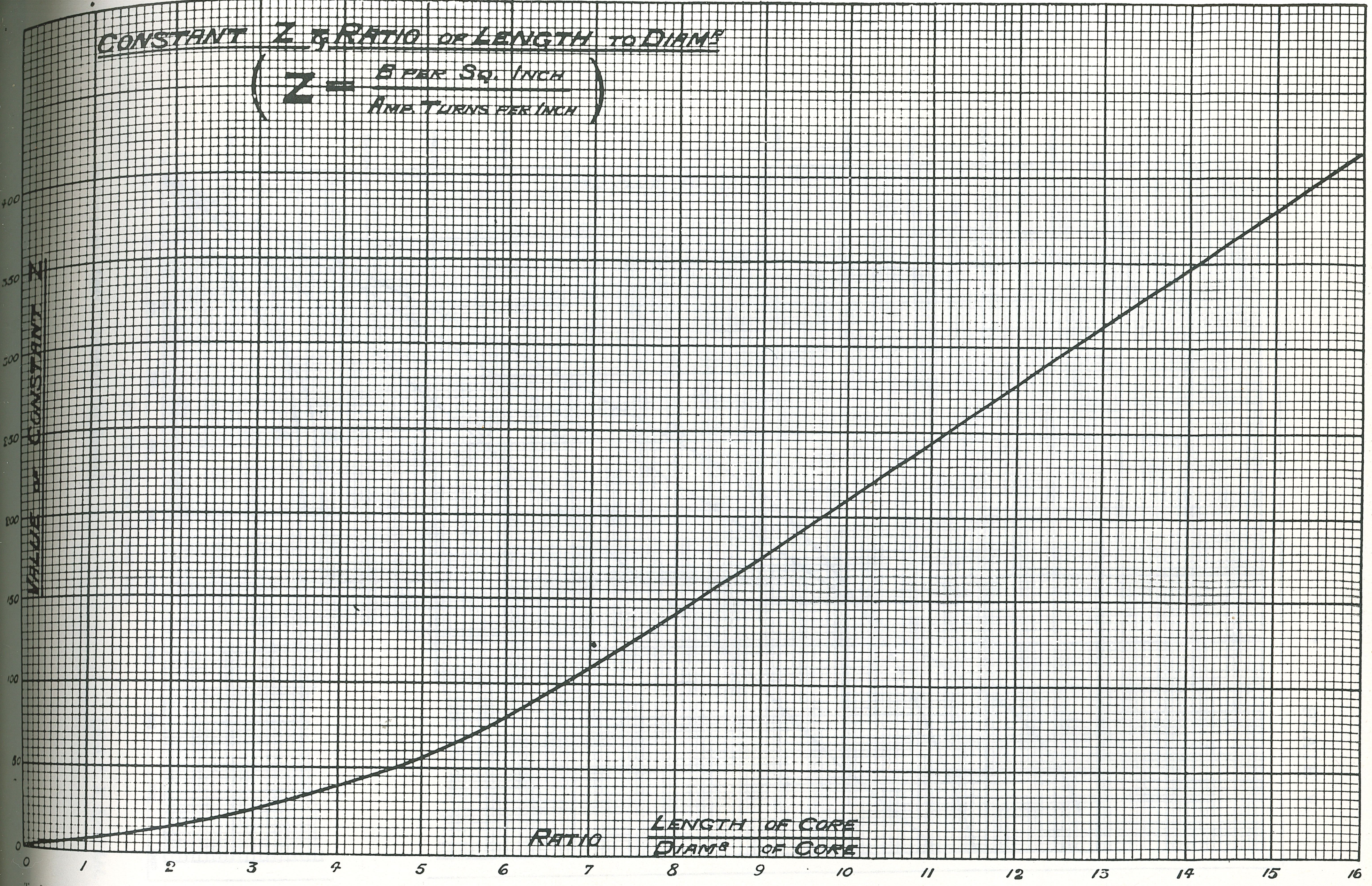


FIG. 70.—Curve of flux density against ampere turns.



To face p. 64. Codd, "*Induction Coil Design*."]

FIG. 71.—Curve of $\frac{L}{D}$ against $\frac{\text{Density}}{\text{A.T.}}$.

[*E. & F. N. Spon, Ltd.*

PLATE V.

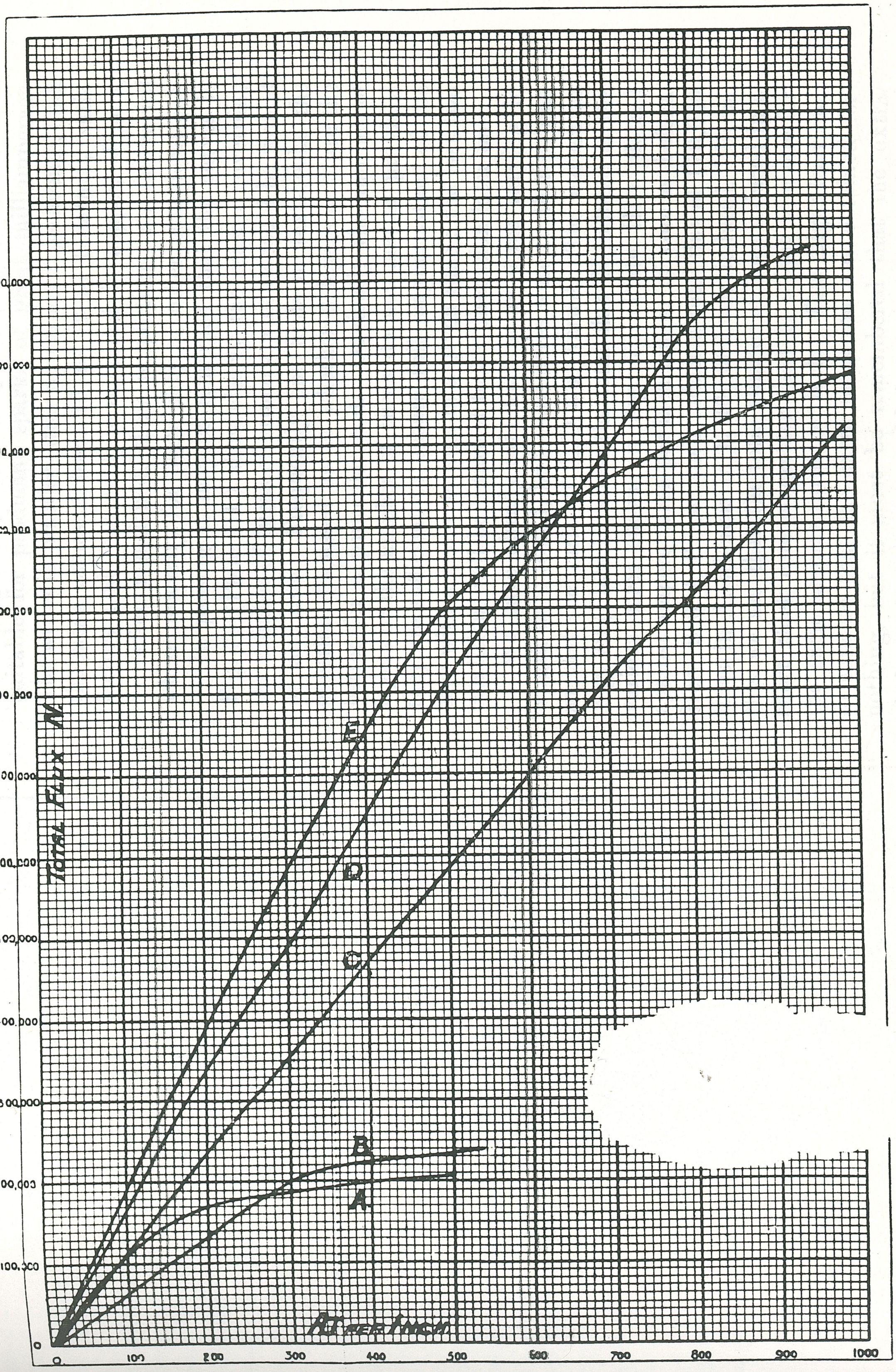


FIG. 72.—Curve of total flux.

To face p. 65. Codd, "Induction Coil Design."] [E. & F. N. Spon, Ltd.

be magnetised. This curve only applies when the core is not saturated.

Broadly speaking, the ratio of L/D varies from 15 : 1 to 6 : 1, the longer coil being chiefly of use in obtaining spark length or pressure only, while the shorter ratio is suitable for producing sparks of great milliamperage. The writer in practice, after numerous experiments, finds the mean values of from 10 to 12 to 1 entirely satisfactory and reasonably economical in copper, though, as before mentioned, these proportions can be varied where necessary for portability or other considerations.

In passing it may be remarked that the curves in Fig. 70 (Plate III.) show clearly the reason governing the number of turns of primary which should be wound on any core. Frequently one finds in text-books the question discussed as to whether 2 layers or 3 are the better for a particular coil. Obviously the number of layers or the number of turns do not matter provided they are sufficient to ensure full magnetisation of the core with a given voltage in a given time ; the last two conditions will be returned to for discussion later on.

We have already said that many cores varying in length were tested, but these cores were further chosen so that the ratio of L/D also varied. The curves in Fig. 72 (Plate V.) show the total flux N induced in the various cores shown in Fig. 70 (Plate III.) plotted against ampere turns per inch length of core as before. Here 200 A.T. per inch induce a total flux of 170,000 lines in A, whereas in E 400,000 are induced. From this we see that the total number of lines induced in a short thick core is greater than in a long thin one for the same ampere turns per inch. This might lead one to suppose that the extra induction was obtained for nothing, but it must be remembered that the extra girth of the coil means added resistance in the primary and greater self-induction hence either a higher E.M.F.

must be applied to bring the magnetisation about, or, as an interrupted current is used, the rate of interruptions must be decreased to allow the current to assume its full value. Therefore for a given weight of iron it is preferable to distribute it so that the proportion of L/D is 10 to 1 to obtain the best efficiency and economy, as above explained.

In discussing the interruptions of the current we propose arbitrarily to assume a rate of interruption, or frequency, of 50 interruptions or periods per second, since much lower frequencies for radiographic work lead to flickering of the screen, and for wireless and other purposes this periodicity is usually high enough for practical purposes.

If, therefore, the frequency of the interruptions of current supplied to our magnet is fixed, and the core diameter is increased to obtain more net lines, it follows that the voltage must be raised to obtain the desired result, which again brings us back to the point at which it may be preferable to make the core longer and thinner.

Further, if the diameter or thickness of the iron be unduly large, the current usually available will fail fully to magnetise it (unless the coil indeed be intended for single-flash work, in which case the core may be heavy or even a closed magnetic circuit, *q.v.*) and the whole apparatus will be heavier than necessary, moreover every inch added to the diameter of the iron (which is cheap) adds proportionately more to the length of the primary and secondary windings which, being of copper, render the coil dearer to produce.

Moreover, the resistance and self-induction of the secondary will be very much greater for the same number of turns than if distributed evenly over a longer and thinner core of the same weight. There is one point, however, which should not be overlooked if the coil is designed solely for X-ray work, that is, the flux density cannot be forced up to the saturation point in a coil for radiography owing to the presence of inverse in the secondary caused by the primary current on "make," unless, of course, a valve is interposed. The reason for this can be seen by examining curve A in Fig. 70. As 2 amperes in the primary chosen produce a flux of 80,000 lines per □″ we get the point Y on the curve XYZ. If more lines are required we must double or treble the current to produce a quite inadequate increase, because Y represents the knee of the curve where it turns over because the iron is nearing saturation. Now it is our aim in radiographic work to magnetise the iron as slowly as possible to eliminate the inverse or "make" current in the secondary. If in the example taken we are satisfied with a current of 2 amperes, we shall obtain a fairly sharp magnetisation rate XY, after which the magnetism ceases greatly to increase; but if we aim at increasing the magnetism still further to Z, along the curve XYZ, the current must be increased to 5 amperes, which will result in a very rapid magnetisation from X to Y accompanied by increased inverse in the secondary. It is manifest, therefore, that for X-ray purposes the last part of the curve YZ is doubly inefficient, since it requires a disproportionate magnetising current and tends to produce inverse in the cathode tube. For this reason most makers are content to work their induction from X to Y only, this generally corresponding with a flux density of from 60,000 to 80,000 lines per □″.

The cores considered up to the present have been open magnetic circuits, that is the magnetism induced in the core has to return through the air, which has a very considerable reluctance, thereby necessitating a very much greater number of ampere turns than if the core were a closed magnetic circuit. To use a core with a closed magnetic circuit has been frequently suggested,

but up to the present has not met with success for induction coil work, owing chiefly to two disadvantages. The first is due to the fact that as the magnetic circuit is a complete one the magnetisation does not die away sufficiently suddenly to induce satisfactory currents in the secondary. The writer has several times tried to obtain satisfactory results by using a second primary winding to polarise the magnetic circuit mildly in an opposite direction to the main primary winding, but without success. It is necessary to reverse the current entirely to obtain a heavy discharge, and this is not practicable up to the present for ordinary coils, although it has been used in connection with large closed magnetic circuit coils for single-flash work. The second disadvantage, less serious, is the difficulty of insulating the secondary when surrounded by the iron core.

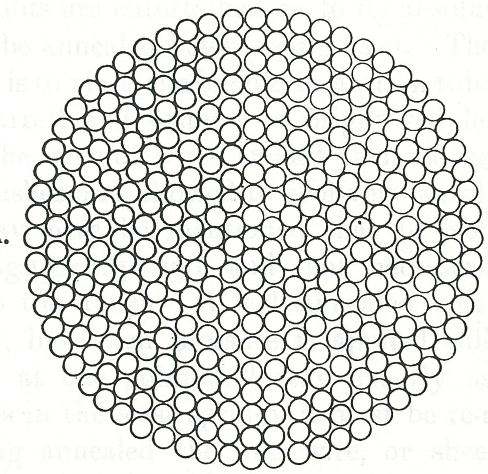
The next step that would suggest itself is to close partially the magnetic circuit, and coils have been constructed, notably by Klingelfuss, on these lines, but they appear slow in action and the writer after many experiments is unable to satisfy himself that there is any real gain to be obtained by this construction. A step further brings us to the method of hedgehogging the iron core at the end so as to close very partially the magnetic circuit and provide as it were jumping-off points for the returning magnetic lines as in the old Swinburne transformer. This method certainly presents few disadvantages, particularly if the coil be oil immersed, but again the advantages derived are so small as hardly to justify its use.

Constructional Details.

The core of the coil is usually made of a cylindrical bundle of soft iron wires carefully annealed, through the centre of which is thrust a stout iron rod to give stability to the whole, and to form a convenient attachment for

the armature or nosepiece which attracts the hammer, where one is used. Some makers employ for large coils soft iron sheets cut to dimensions which allow of the core

A.



B.

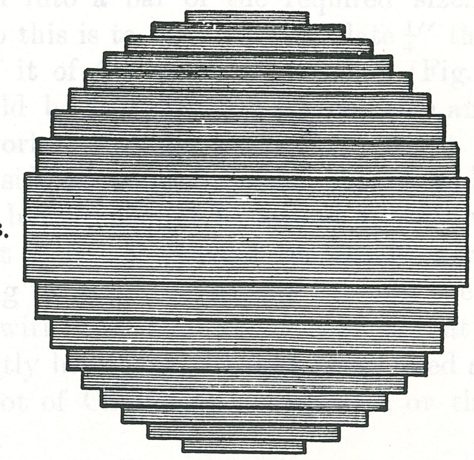


Fig. 73.

A. Circle containing circular iron wires.
B. Circle containing flat strips, of equal diameter.

being built up approximately of circular form, the reason being that thereby a greater quantity of iron can be placed in a given space. The effective area of iron A which

can be placed in a circle of diameter d, when circular iron wires are used, is given by the formula—

$$A = \frac{\pi}{4}d^2 \times \cdot 75 = \cdot 589d^2 \qquad \text{(Fig. 73, A.)}$$

and when sheet iron is used, by

$$A = \frac{\pi}{4}d^2 \times \cdot 9 = \cdot 706d^2 \qquad \text{(Fig. 73, B.)}$$

In any case the iron chosen should be as soft as possible to avoid hysteresis losses and of the highest permeability to ensure the greatest magnetic flux with the least expenditure of current, a point more than usually important in view of the short duration of contact called for with modern interrupters. Moreover, the core should be carefully subdivided to avoid eddy currents in its mass in which wire is rather better than sheet iron. When laminations are used each lamination should be carefully varnished to prevent conducting contact with its neighbour. Stalloy and Lohys laminations are usually supplied with an insulating coating already applied. Soft iron wire does not require any special treatment, as the skin of rust which forms on annealing is sufficient to prevent conduction of the low pressure eddy currents which might tend to form. Some makers boil the core in wax or soak it in varnish, but there does not appear to be any gain electrically although it stiffens the core for winding. The gauge of iron wire used is usually about No. 22 or 24 for small and medium sized coils up to say 16″, and 20 or 18 gauge for large coils above that size. In coils used on specially high frequencies, however, gauges as fine as 36 or 40 are sometimes specified, but beyond the fact that there is a slight gain in iron owing to the better space factor the writer has been unable to discover any benefit in the employment of these finer sizes which are, moreover, awkward to handle and much more expensive. Generally speaking, No. 22 may be taken as a good working size in both wire and sheet iron. On receiving the core iron, if any doubts are entertained as to its absolute softness it should be annealed before being used. The best way to do this is to place the bundle in an iron tube (a length of gas barrel) and bring to a bright red heat on the forge. The tube of wires should then be well covered with hot ashes and allowed to cool very slowly.

It may here be mentioned that by soft iron we mean magnetically soft and not necessarily a wire pliable to the touch. A well-annealed soft iron wire feels hard, but when pressure is applied will suddenly give way at one point and stay exactly as bent; if the wire is in the least springy it must be re-annealed.

Having annealed the iron wire, or sheet, it must be formed into a bar of the required size. The best way to do this is to take an iron plate $\frac{1}{4}''$ thick, having a hole in it of the required diameter (Fig. 74). The hole should be bell-mouthed on one side and the iron bundle worked through gradually. As it appears on the other side of the plate (which should be held in the vice) the bundle should be wound spirally with cotton tape about $\frac{1}{2}''$ lap, to prevent the bundle springing out. Continuing to work the bundle through the gauge and winding with tape the whole core can at length be conveniently bound up, the tape being fixed at each end with a spot of Chatterton's compound, or the like, and varnished.

If an iron rod is required this should first be located in the centre of the core, the bundle being roughly bound with a few turns of wire, as it will be found practically impossible to force the rod in after the core is bound with tape.

In some cases it is desirable to form a channel down the side of the core to accommodate a return for the end

of the third layer of primary, in which case an insulating tube should be placed in position, the whole being worked through the gauge and taped up. The core is

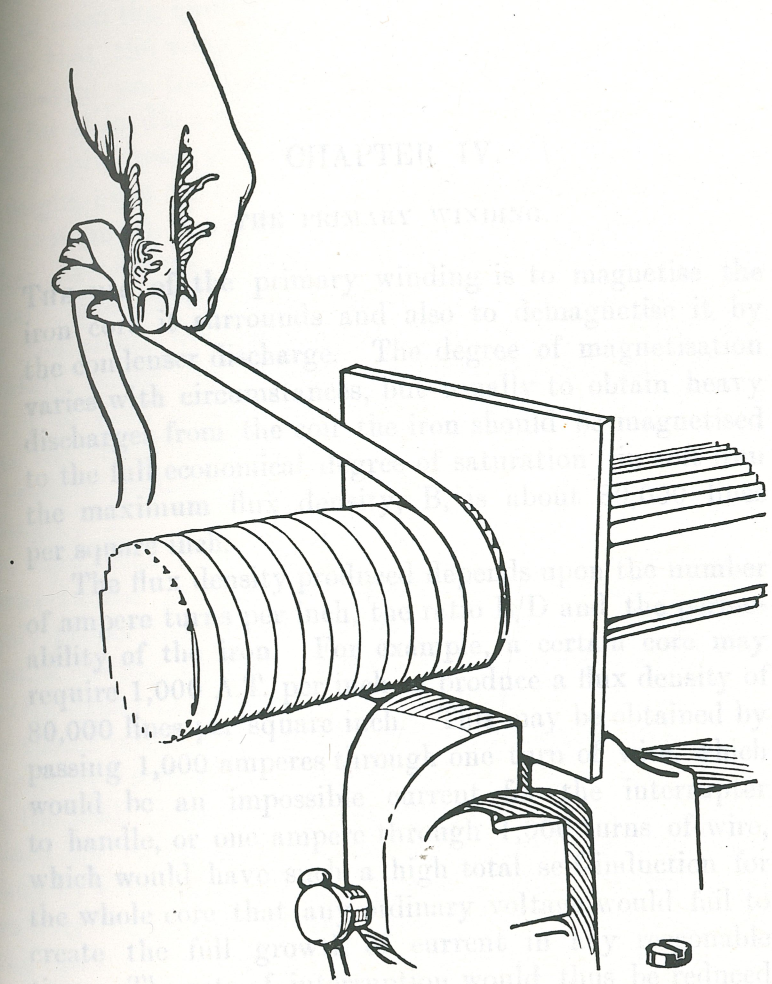


FIG. 74.—Showing method of taping core after forcing through a gauge plate.

then ready to receive the insulating covering on which the primary is wound. For small coils of up to 3″ or 4″ spark, working in a low primary voltage, a good

lapping of tape well soaked with shellac or Major's varnish is sufficient, but for coils which may be required to work off the mains at pressures of from 50 to 250 volts a better insulation is required, and this may consist of two or more turns of 4 mil varnished cloth or the like, depending on the voltage to be used and the method of subdividing the primary.

CHAPTER IV.

THE PRIMARY WINDING.

THE use of the primary winding is to magnetise the iron core it surrounds and also to demagnetise it by the condenser discharge. The degree of magnetisation varies with circumstances, but usually to obtain heavy discharges from the coil the iron should be magnetised to the full economical degree of saturation; in soft iron the maximum flux density, B, is about 80,000 lines per square inch.

The flux density produced depends upon the number of ampere turns per inch, the ratio L/D and the permeability of the iron. For example, a certain core may require 1,000 A.T. per inch to produce a flux density of 80,000 lines per square inch. This may be obtained by passing 1,000 amperes through one turn of wire, which would be an impossible current for the interrupter to handle, or one ampere through 1,000 turns of wire, which would have such a high total self-induction for the whole core that any ordinary voltage would fail to create the full growth of current in any reasonable time. The rate of interruption would thus be reduced to an impracticably low degree, hence some balance must be struck between the two, probably of the order of 10 amperes and 100 turns. A second factor comes into play in the calculation of the primary ampere turns, since the voltage V_p induced in the primary

winding at break is proportional to the voltage V_s induced in the secondary at the instant of sparking. Further, if magnetic leakage is neglected the ratio of the voltage in the secondary to the voltage in the primary is equal to the ratio of the number of secondary turns to the number of primary turns, that is

$$\frac{V_s}{V_p} = \frac{T_s}{T_p}$$

Therefore, to keep the number of secondary turns low, as is desirable, the number of primary turns must also be kept low, but this will mean a heavy current to obtain the necessary ampere turns, hence this method of procedure cannot be pursued beyond a certain definite point. On the other hand, if the number of turns on the primary are increased to effect current economy we get (1) a slowing of the rate of interruptions unless the applied voltage is raised, (2) a heavy induced primary voltage likely to pierce the insulation of the windings and condenser, and (3) a larger number of secondary turns, having increased self-induction and resistance. From practical experience the writer has found the best transformation ratio to be of the order of 150 to 1, although this may be altered to suit varying conditions. For example, this ratio may be higher for exciting cathode tubes and lower for wireless coils. The proportions indicated above give a valuable guide to the voltage induced at break over the primary, thereby enabling us to place our insulation to the best advantage. As an example, suppose a 10″ coil to be under consideration having a transformation ratio of 150 to 1. From the curve of Plate I. we see that 10″ corresponds to a striking voltage of about 148,000 volts, dividing this by 150 we get the voltage over the primary as 986 volts at the moment of interruption. From this we see that as the spark gap is increased so are the primary

volts and this explains how it is that the primary and condenser are more likely to break down when a long spark is taken than when a short one passes.

At first sight it might be assumed that this formula gives at once the number of primary turns; but it will be seen that the voltage induced in a given secondary is dependent on the total magnetic flux, and the time taken for it to die away, irrespective of the number of primary turns used to produce the magnetic flux. The flux might even be produced by external means, such as a permanent magnet. Pursuing this argument another step we see that if we double the number of magnetic lines in the core, keeping the time of dying away the same, we always double the voltage in the secondary, since the voltage depends on the total number of lines cut, and the time taken to cut them. Hence the transformation ratio is only useful as giving the relative voltage over the primary and secondary windings.

It may thus be taken that the sparking voltages induced in the primary and secondary windings are roughly proportional to the number of turns T_p and T_s, although, owing to the transient values, considerable difficulty exists in measuring them. Figs. 49, 50, 51 show values obtained by shunting the oscillograph over the primary break through a high non-inductive resistance, the peak value corresponding very nearly to that obtained by calculation. These results were further checked by connecting a spark gap with blunt needle-points over the primary winding, and gradually decreasing the distance between the points by a fine-cut screw thread till the voltage induced in the primary struck across the gap. This gap was then removed and connected to a transformer and electrostatic voltmeter, the pressure being raised gradually and noted exactly when it was sufficient to jump the gap. This reading

was multiplied by 1·414 to obtain the peak value, and the result tallied sufficiently with the other results obtained to prove the point conclusively.

Constructional Details.

To wind the primary or the core of any but very small coils some form of winding machine is necessary, a lathe, particularly if back-geared, being as useful for this purpose as any. Fig. 75 shows a form of apparatus which is very convenient to handle. It consists of a double bearing carrying a mandrel threaded at one end to support a wooden chuck and cranked at the other to

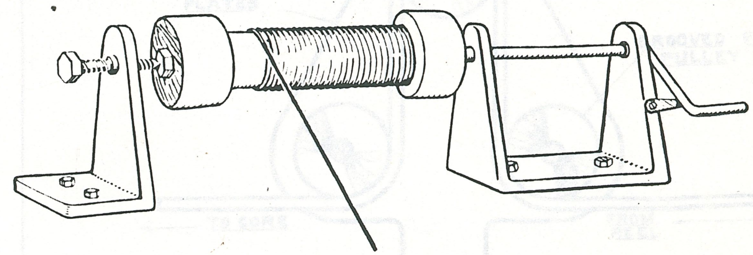


Fig. 75.—Winch for winding primary

form a handle. Situated on a plank, the requisite distance away, is a tail stock with a pointed screw, which bears on a second wooden chuck. These chucks are wooden discs cupped out to fit tightly over the core for about $\frac{1}{4}''$, and can be readily slipped off when the primary is wound. A trigger at the side serves to hold the handle in place to prevent unwinding should the operator have to leave the machine. All being ready, and the core having been heavily taped, or otherwise insulated, the end of the primary wire is bent round the core, leaving a few inches free for making connection, and this free end should be tightly tied down to the wooden chuck to keep it out of the way, and also to give a drive should the core tend to slip round in the chuck. Two short pieces of tape should

be cut off and folded round the first turn of the wire at opposite ends of a diameter, and the machine rotated so that succeeding turns trap the tape and hold the first turn in position, as shown in Fig. 76. The tape used should be Egyptian cotton tape for large coils and silk for small ones. If the primary is a very large one it may be fixed at three or even four points to prevent unwinding. The primary wire is then wound evenly on for the whole length of the core. If the wire is very stout, say over 14 gauge, it is desirable to have some method of tensioning the wire, as the size of the larger gauges quickly tires the hands. One method is to fit a friction brake to the drum containing the wire; but a better method is to rig up three small fibre pulleys as a sheave (Fig. 77), the whole arrangement being held with both hands while another operator turns the winding machine. If the wire is desired to lie exceptionally closely, it will be necessary to knock it up from time to time with a hammer and gadget. This latter is a small chisel-ended tool, made of fibre so as not to damage the insulation; but even so it must be used with care, or the cotton covering may be abraded. The first layer being complete, the operator should satisfy himself that the coil is truly circular without bumps or irregularities, and count the number of turns. The whole should then be bound over carefully with insulating tape, giving a half lap or more, according

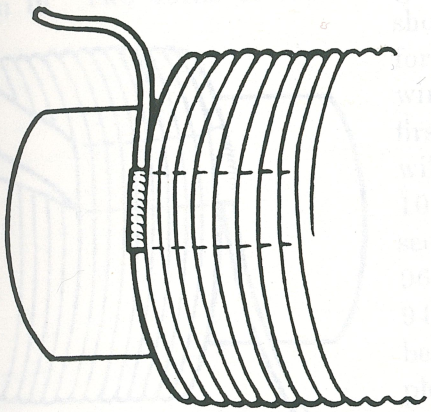


Fig. 76.—Method of securing the beginning end of primary by tape loops.

to the size of the coil. Small coils, giving sparks up to 4″, do not need any covering between the layers, although a turn or two of paper may be interposed for additional safety, as the cotton covering of the wire is usually sufficient insulation. The second layer can now be proceeded with, and so on. Before taping each layer it is sometimes advisable to brush over the winding with shellac or other insulating varnish; but if the insulating tape between the layers

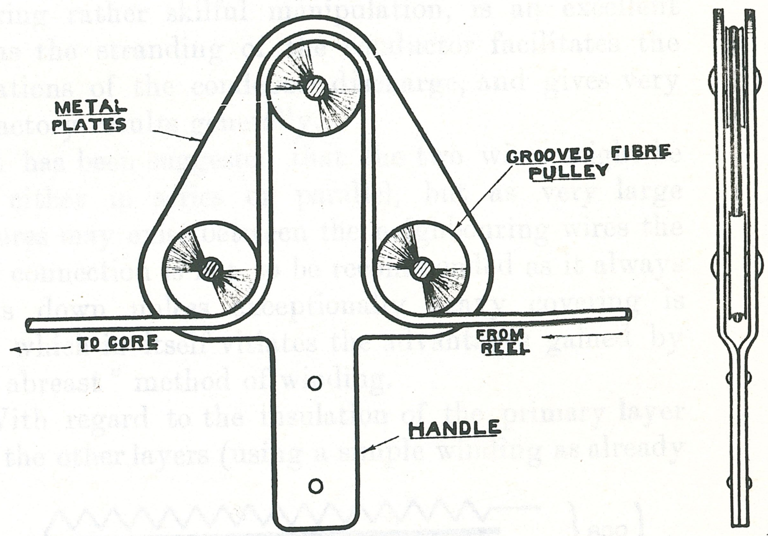


Fig. 77.—Tensioning sheave.

is of good quality varnishing can usually be dispensed with. When the winding nears the end of the last layer the machine should be stopped about five or six turns from completion, and two or more folded tapes laid on the core, allowing the bight, with a fair amount of slack, to hang over the end of the core. The machine must now be rotated to trap the tape, the raw ends of the tape protruding between two successive spirals, and the remaining turns wound on, leaving, as before, a few inches loose for connection (Fig. 78). The free end must now be threaded through the loops

of the tapes, and the raw ends seized firmly by a pair of flat-nosed pliers and pulled hard, taking care not to break the tape which should slide along under the last five or six turns and bring the finishing turn up alongside in a shipshape fashion. The number of turns should be counted, and the whole entered in a book for reference. It will be found that each layer has to be "drawn in" two turns to make a good job, and this should be allowed for when estimating windings—thus the first layer of a coil will contain, say, 100 turns, the second 98, the third 96, and the fourth 94, etc. The coil, being now completed, may be released from the machine, and served with a good coating of insulating varnish. It is advisable to tape the outside of the very large cores, as their weight makes them difficult to handle, and renders them more liable to be bruised and abraded when sliding them into the primary tube. In some coils silk-covered wire is used to obtain a better space factor; but, unless an exceptional degree of compactness is desirable, it is better to use a cotton covering, preferably double cotton, to avoid any likelihood of breakdown.

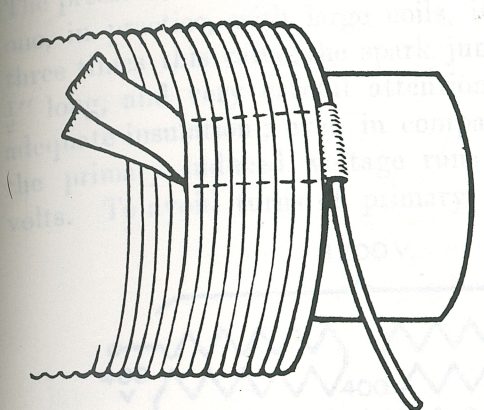


FIG. 78.—Method of securing the finishing end of primary by tape loops.

The above instructions are intended to apply to coils wound in the usual manner with round wire in layer windings; but there are various modifications still to be considered. Firstly the shape of the wire. This is most conveniently of round section, but obviously a square section gives a higher current-carrying capacity for the space at our disposal, and is sometimes used on this account. Square wire is, however, rather difficult to handle, especially if it once becomes kinked, and the covering is rather likely to fray at the corners unless exceptional care is taken.

The second modification consists in winding two or more smaller wires side by side or abreast, their total area equalling the gauge required. This method, though requiring rather skilful manipulation, is an excellent one, as the stranding of the conductor facilitates the oscillations of the condenser discharge, and gives very satisfactory results generally.

It has been suggested that the two wires might be used either in series or parallel, but as very large pressures may exist between the neighbouring wires the series connection is not to be recommended as it always breaks down unless exceptionally heavy covering is used, which in itself vitiates the advantages gained by the "abreast" method of winding.

With regard to the insulation of the primary layer from the other layers (using a simple winding as already described), it is necessary to make some calculation as to the magnitude of the electrical stresses set up. Suppose the winding to consist of three layers as shown diagramatically in Fig. 79, and that the calculated voltage induced is 1,200 volts between the two ends of the primary. Each layer will then give a pressure of 400 volts, the maximum pressure between the adjacent

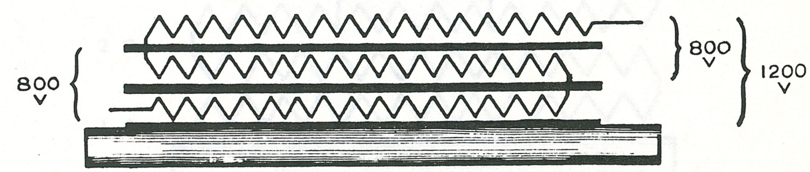


FIG. 79.—Voltage distribution in three-layer primary.

ends of any two layers being 800 volts and the insulation of tape or other dielectric must be sufficient to withstand this pressure. It will be noticed that the difference in pressure between the ends of the first layer wound in the core is 400 volts. If, however, the coil is wound with 4 layers the voltage in each layer will be 300 volts and the pressure between 2 layers 600 volts. The pressure of 1,200 volts instanced is a very moderate one, in practice, with large coils, it may easily reach three times this value, the spark jumping over surfaces ½″ long, and very careful attention must be given to adequate insulation; even in comparatively small coils the primary induced voltage runs into hundreds of volts. To avoid turns of primary differing greatly in

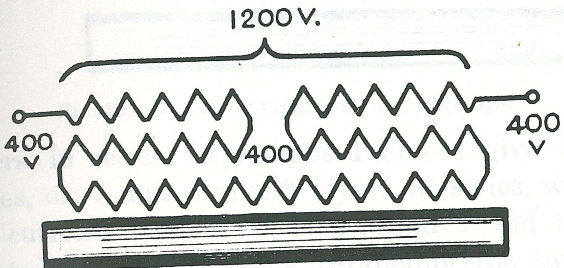


Fig. 80.—Sectional primary correctly arranged.

voltage being placed adjacently, various methods have from time to time been suggested, the principle being the subdivision of the primary into sections in a similar manner to that subsequently described for secondary windings. Fig. 80 shows a primary winding so subdivided; here the winding of three layers is divided into two, the pressure as before being 1,200 volts, then there will be a voltage of 200 volts per layer, or, 400 volts between the adjacent ends of two layers instead of the 800 volts obtained by the single layer method, and it will be noticed that a pressure of 400 volts only is still applied to the insulation round the core. The method of winding shown in Fig. 81 necessitates a cross-over

wire in the centre and the pressure of the terminal ends immediately adjacent to the core rises to 800 volts. It has been suggested that this subdivision of the primary might be carried still further, but sectional

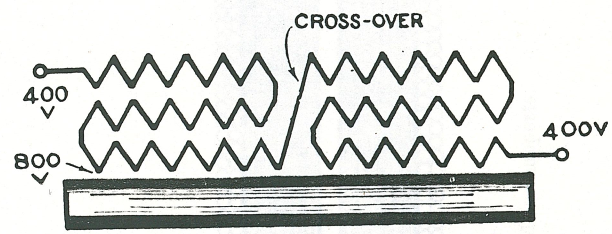


Fig. 81.—Sectional primary incorrectly arranged.

primaries are rarely used for two reasons: first, the additional space taken by the soldered ends is better used by a plain winding and improved insulation between the layers for the same space; and secondly, a sectional winding cannot be tapped off or paralleled, as to use half of the winding only when section wound would mean that only one-half of the core would be magnetised and this unsymmetrical field would give

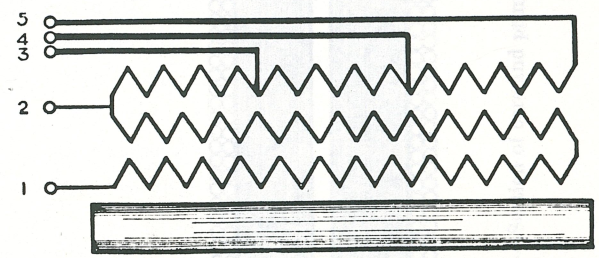


Fig. 82.—Method of tapping incorrectly arranged.

poor results. In general, primaries are almost always layer wound in order to place the layers in series or parallel.

The method of tapping the primary is open to the same objections as section winding. In Fig. 82 we have a core wound with 2 layers and the third tapped off in three positions. It will readily be seen that the

only symmetrical connections energising the whole core are 1, 2 and 5, since 3 and 4 only excite one-and-two-thirds of the core length respectively. Moreover, the return leads of the tapping take up room and have to be carefully insulated from the underlying windings.

Perhaps the best method of winding a large primary, particularly when the voltage on which the coil is to be used is variable, is to use 4 layers as shown in Fig. 83. Here terminals 1 and 2, also 3 and 4, give

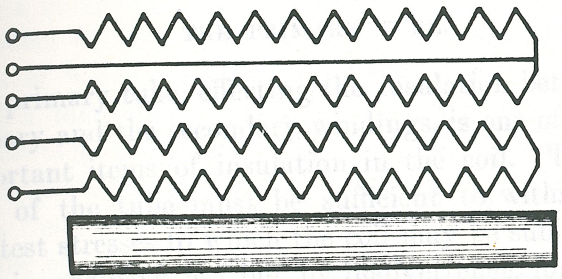


Fig. 83.—Method of tapping correctly arranged.

2 layers in series. Terminals 1 and 4 give 4 layers in series, or, 1 and 5 give 3 layers in series, while for heavy currents terminals 1 and 3 and 2 and 4 can be connected together, thereby paralleling the two windings and giving two layers both in parallel. Should one layer only be wanted for any purpose terminals 4 and 5, or 3 and 5, will furnish the required layer.

In some coils the ends of the primary are led out at each end, the windings often being laid on all in the same direction, the ends being taken to studs which can be placed in series or parallel as required. This method is conducive to external sparking, unless the primary tube is fairly long, and it is always best to locate all primary ends and terminals at one end of the tube, leaving the other end of the primary tube to be sealed with wax or other insulating medium. The general finished appearance of a medium-sized primary and core is shown in Fig. 84.

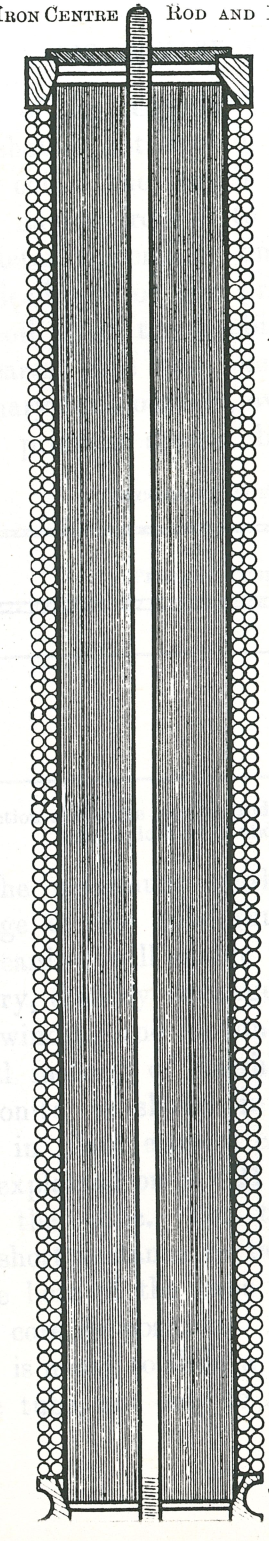


Fig. 84.—Section of core and primary with fibre ends and iron centre rod and supports.

CHAPTER V.

THE PRIMARY TUBE.

THE primary tube, effecting the insulation between the primary and the secondary windings, is one of the most important items of insulation in the coil. The thickness of the tube must be sufficient to withstand the greatest stresses to which the coil may be subjected, not only in ordinary use but by inadvertence, for instance the accidental earthing of one end of the secondary on full spark gap. The thickness should, however, not be unreasonably in excess of that required, as the effect will be to separate unduly the distance between the primary and secondary windings which should be as closely coupled as possible. The material of the tube should lend itself as much as possible to amalgamation with the wax insulation used on the secondary, so as to prevent the possibility of internal shorting along the surface of the tube, also the tube should be capable of withstanding a moderate degree of heat generated in the primary without losing its insulating properties.

Generally speaking, ¼″ thickness of micanite or the finest ebonite can be allowed as sufficient for 12″ of spark length, since the maximum pressure will not much exceed 6″, unless one end of the secondary is wilfully earthed on full gap.

If for certain reasons, such as for wireless purposes or for safety in X-ray operations, it is necessary to

earth one pole of the secondary, the maximum spark length taken should not exceed half the rated spark length of the coil. The length of the primary tube may be taken as far from 2 to 2·5 times the spark length, the factor depending on the length of the core and the lead out of the primary wires, and on whether the coil is of the bobbin type or poured in solid. The nearest path from one end of the secondary along the primary tube outside, over the edge and back inside to the primary should be in excess of 1·33

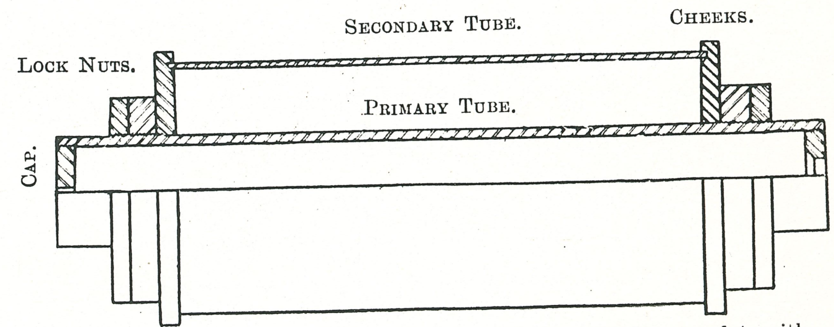


FIG. 85.—Semi-section of ebonite primary and secondary tubes complete with cheeks, lock nuts, and caps.

times half the maximum spark length, or else the surface leakage of the tube (and this is particularly high with micanite) will enable the spark to flash over to the primary, thereby endangering the insulation of the primary winding and its condenser.

The usual method of finishing the primary tube when of ebonite is shown in Fig. 85. After the secondary is in place ebonite cheeks are threaded on the tube as explained on p. 121 and ebonite lock nuts screwed on the tube. The tube is also threaded internally a short distance to take ebonite caps which block up the bore of the tube and serve to keep the primary and core in position. As micanite cannot be machined it is usual to slide a thin ebonite tube over the micanite tube, not only to reinforce it and render

it able to be machined, but also to eliminate as much as possible the high surface electrification causing leakage and flashing over to which micanite is so prone.

As coils of the larger sizes necessitate very large primary tubes the cost becomes very high and in ebonite the insulating properties do not increase in proportion to the size used. A better tube can be made by rolling the best ebonite sheet about $\frac{1}{32}''$ to $\frac{1}{16}''$ thick on a roller, the sheet being manipulated and rolled on a hot plate, or failing that a large bath of hot water, sheets of ebonite being added till the required thickness of wall is attained. Although the result is not such a mechanical job as a machined tube, it is very much stronger dielectrically, and can be rendered neat in appearance by treating it in the same way as micanite, that is by sliding over the ends of the completed tube sleeves of solid tube machined to the desired requirements for caps, etc., complete.

With proper impregnating plant it is possible to make tubes of paper rolled up under the surface of the insulating wax, etc., which are superior in dielectic strength to ebonite. Paxolin tubes so treated can be obtained (see Insulating Materials).

Tubes of glass and porcelain have been used, but owing to their brittleness and intractability have not found much favour.

For small coils tubes of manilla paper well shellacked or boiled in hot wax form an excellent substitute for ebonite, particularly as the smaller coils are usually of the poured-in sort, which do not require much mechanical finish.

When designing the primary and secondary windings care must be taken to ascertain the maximum and minimum dimensions of the bore and diameter of the larger size tubes, as these being constructed on taper mandrels may vary as much as $\frac{1}{8}''$ in diameter between

the ends, so that the windings if too good a fit may enter one end, but will not slide the full length of the tube.

Whatever kind of tube is used care must be taken to test it thoroughly before using (see Testing), as in the event of its puncturing the whole of the coil and the labour expended thereon is wasted.

CHAPTER VI.

THE SECONDARY WINDING.

THE size of the secondary coil, that is its length, diameter and bore, are easily determined. The length should not be less than the required spark length and since surface leakage occurs in damp weather the actual minimum distance between the ends of the coil should not be less than 1·33 times the required spark length, thus the secondary of a 10″ spark coil should be from 13″ to 14″ long.

Fig. 69, Plate II., shows the effect of using test coils of varying diameters, but of a fixed number of turns on a core having a ratio of 8·14 to 1. It will be noticed that the voltage induced in each of the coils falls off considerably as the end of the core is reached. The dotted lines AB indicate the best theoretical length of the secondary, but as previously explained, this has to give place to practical considerations, on the one hand the probable inconvenient length of the core, and on the other the necessity of increasing the length of the secondary to avoid internal and surface leakage.

As previously laid down on p. 62 the exact length of the secondary should be 80 per cent. of the true magnetic length of the core.

The ratio of the diameter to the core is more difficult to determine, but reference to the curves in Fig. 69 shows that the efficiency of the turns of secondary wire

decreases considerably with their distance from the core, hence the smaller in diameter the turns can be kept the greater will be the output apart from the saving in wire.

We see, therefore, that the secondary turns should be as near the core as possible, and we may now examine various forms of winding to ascertain the best method of obtaining the desired result. Methods of coil winding may be divided under two heads: layer winding and section or spiral winding; and the mode of assembling into one-section, two-section, and multisection coils.

The easiest method, and the one usually employed in the manufacture of very small coils, is the one-section layer winding (Fig. 86). Here we have the turns of

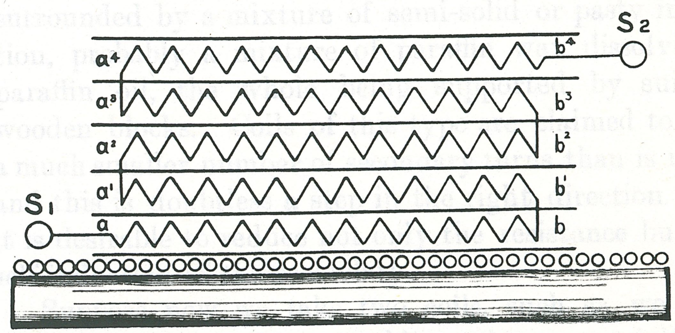


FIG. 86.—Diagram of simple layer winding one-section.

secondary wound in layers, each layer being insulated from the next by one or more turns of paper *a-b*, *a′-b′*, etc., until the desired number of turns has been wound on. Let us imagine the coil under consideration gives a 1″ spark, then if it is composed of 5 layers of winding (it would in practice have about 50 layers) each layer will give $\frac{1}{5}''$ spark and at the point of maximum pressure, the ends, each sheet of insulation will have to withstand twice this pressure, or $\frac{2}{5}$, since 2 layers are here superimposed. Suppose this difficulty overcome, there remains the objection that the height from

a to a^4 and b to b^4 must be greater than 1″, or else the spark will strike over the ends of the layers, and, allowing for surface leakage, the height should be at least 1·33″ for safety. Thus, where a 10″ coil so wound, the height of winding would have to be 13·3″ high, giving a diameter of say 27″, exclusive of the core and primary. It can be argued that by extending the edges of the paper layers a further considerable obstacle to the spark can be interposed, and this is to a certain extent true, but in practice not enough to warrant its use as the projecting ends of paper become so unwieldy as to

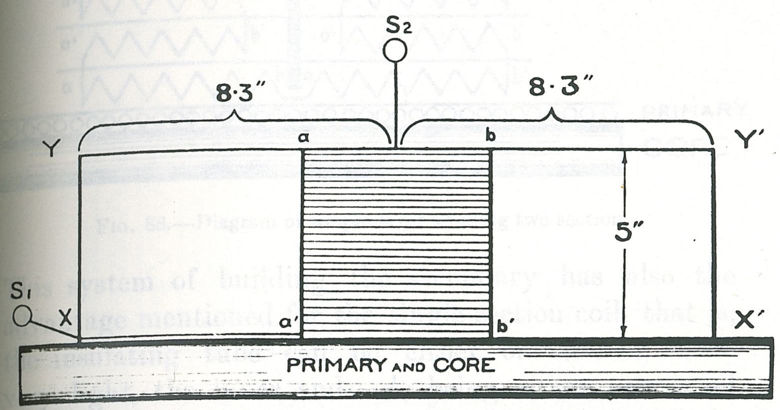


FIG. 87.—Diagram of simple layer winding of large spark length.

defeat the object. For example, Fig. 87 shows a coil we are attempting to insulate, giving a 10″ spark, the winding space of which we will assume to occupy a length a b of 5″, and a height a a'—b b' of 5″, then it is clear, assuming the minimum leakage path to be 13·3″, that since the radial height is 5″, the height XY of the insulation (layers of paper) must also equal 5″, therefore the difference 8·3″ must be made up by half the length of the coil to where the secondary end emerges, that is the total length of the coil is about 17″, which is considerably greater than can be obtained by other methods of winding.

Before leaving this method of winding one great advantage must be observed, namely the absence of any insulating tube between the primary and the secondary, thereby enabling the secondary to be placed in an almost theoretically perfect position in respect to the core, an ideal arrangement, especially as the inner end of the secondary can be connected directly to the primary or "earthed," so that the other end is at full potential above that of the earth. Such a single section coil is sometimes called a unipolar coil and is frequently used in small coils for ignition purposes. The only exception to the writer's knowledge are the large coils constructed by Rochefort, wherein a single secondary section is mounted vertically in a glass vessel and surrounded by a mixture of semi-solid or pasty insulation, probably a mixture of paraffin wax dissolved in paraffin oil, the whole being supported by suitable wooden blocks. Coils of this type are claimed to have a much smaller number of secondary turns than is usual, and this is doubtless a step in the right direction since it is desirable to reduce not only the resistance but the self-induction of the secondary.

Suppose now we take two coils, such as we have been considering, by assembling them co-axially on a core side by side, we shall have the arrangement shown in Fig. 88, that is, a two-section coil. If, as before, the whole coil gives a 1″ spark the two sections each will only have to give a $\frac{1}{2}$″ spark, therefore other conditions being equal the tendency to break down will be reduced about 50 per cent., the point of maximum pressure being between a^4 and b^4. For this reason a washer of ebonite P of sufficient diameter to stop the spark is usually placed between the sections. The risk of sparking over the edges of the paper layers is surmounted by sealing up the sides of the coil sections with wax and not by unduly lengthening the end of

the paper layers as was hypothecated in the single-section coil. Since each section gives only half the total pressure obtained between the secondary terminals, this method works very well in practice and coils of up to 12″ spark gap have been successfully constructed.

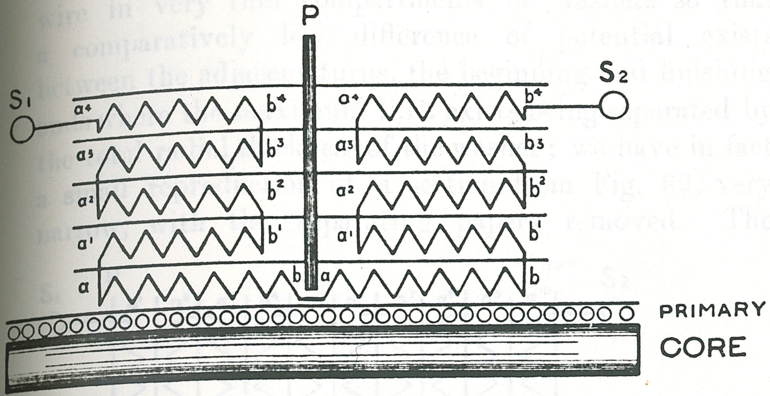


FIG. 88.—Diagram of simple layer winding two-section.

This system of building the secondary has also the advantage mentioned for the single-section coil, that is, the insulating tube can be either omitted or made very light, the inner ends *ab*, being either connected together or earthed, S_1 becoming then the positively and S_2 negatively electrified, each terminal, in other

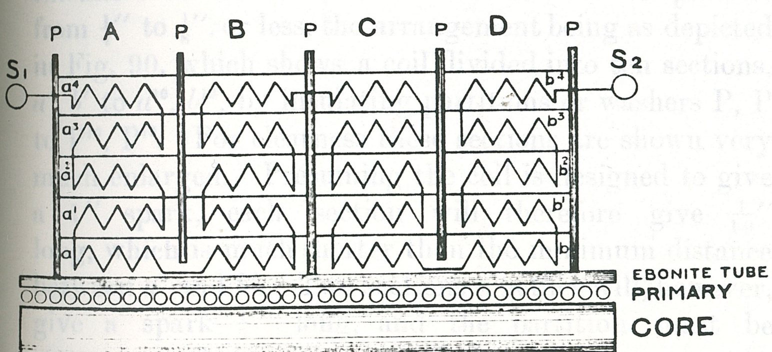


FIG. 89.—Diagram of simple layer winding four sections.

words, being at the same pressure, the one above and the other below earth potential respectively.

If we employ more than two sections we have the multisection layer wound coil shown in Fig. 89, which represents in this case four sections A, B, C, D. It will be noticed that we have now to insert an insulating tube between the secondary and the primary, because if the complete coil gives a 1″ spark, each of the four sections gives $\frac{1}{4}$″, there will be a pressure between the inner turns of $\frac{1}{2}$″ which has necessarily to be insulated from the primary, moreover insulating washers P, P have to be inserted between the sections, since the difference of pressure of $\frac{1}{2}$″ exists on the outside between AB and CD, and also on the inside between B and C. The insertion of the primary tube prevents the secondary winding being arranged quite so close to the core, but in a coil of any size the difference is so small as hardly to signify. In winding the coil as above described, it will be seen that the maximum spark any one section has to give is $\frac{1}{4}$″, that is the difference of pressure between the winding of layer a and layer a^4 equals $\frac{1}{4}$″, as against the $\frac{1}{2}$″ of the bisectional, and the 1″ of the unisectional coils already described. As the distance radially between a^1 and a^4 is probably considerably in excess of $\frac{1}{4}$″ it will be seen that the risk of surface leakage and sparking from layer to layer is considerably diminished and where the coil is further subdivided into say 8 or more sections the risk is practically non-existent, the chief difficulty being in insulating the coils longitudinally by means of the washers P, P already mentioned. Having now described the various forms of layer winding, we will next examine the more usual section winding, or as the writer prefers to call it spiral winding in contradistinction to layer winding.

Section Winding.

Section winding appears to have been introduced almost simultaneously by Apps, Richie, and Siemens and Halske, and consists of fortuitously winding covered wire in very thin compartments or washers so that a comparatively low difference of potential exists between the adjacent turns, the beginning and finishing ends where the maximum P.D. exists being separated by the total radial thickness of the washer; we have in fact a small reproduction of a section from Fig. 89, very narrow, with the separating papers removed. The

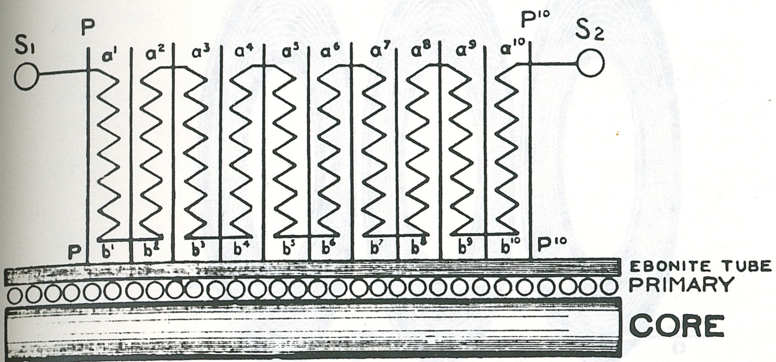


Fig. 90.—Diagram of 10-compartment section winding.

thickness of these washers varies in common practice from $\frac{1}{4}''$ to $\frac{1}{8}''$, or less, the arrangement being as depicted in Fig. 90, which shows a coil divided into ten sections, a', b' to a^{10}, b^{10}, by insulating partitions or washers P, P to P^{10}, P^{10}. For clearness these sections are shown very much enlarged. Presuming the coil is designed to give a $1''$ spark, each section will therefore give $\frac{1}{10}''$ long, which is much shorter than the minimum distance between a' and b'. Two sections together will, however, give a spark $\frac{1}{5}''$ long, and the partition must be strong enough to withstand this pressure, moreover the partition between the points b^2, b^3 and a^1, a^2, where this

maximum pressure exists, must protrude sufficiently to prevent the spark jumping over the edge of the partition. This projection is immaterial and easily arranged at the outside circumference, but on the inside the necessary projection has the effect of removing the inner turns of winding rather far from the core, more especially as the insulation is complicated by surface leakage along the primary tube, even if the total length be made 1·33 times the spark length as before explained, because the air, which sooner or later insinuates itself between the winding and the primary tube, becomes ionised and tends to conduct along the surface of the primary tube.

The effect of this leakage is, in time, to burn through the partition if it is not deep enough, and this spreads from section to section

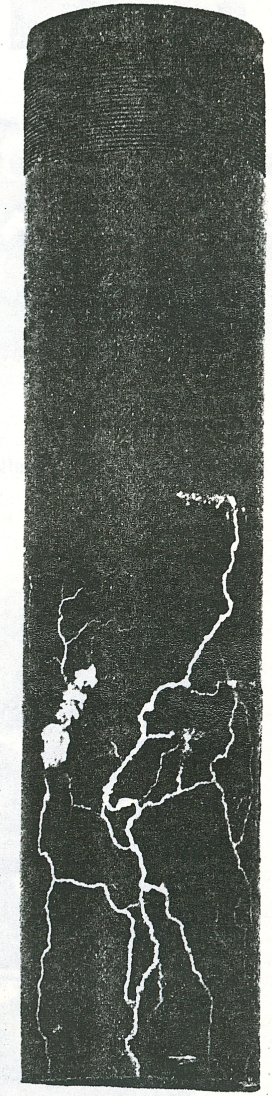


Fig. 91.—Photo of primary tube burnt by internal secondary breakdown.

till the coil is ruined. The primary tube of a coil so burnt out is shown in Fig. 91. Another defect of this method of winding is, that usually the wire is fed fortuitously into the space between the partitions, as will be subsequently explained, and occasionally a wire may slip down and form the chord of an arc, so that instead of a pressure of a few volts existing between the turns a considerable pressure may be applied between the turn which has slipped down and the adjacent windings, in which case a burn out is sure to ensue. The reader will notice we have now arrived

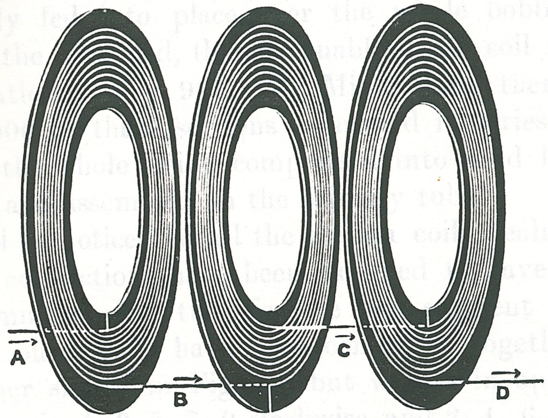


FIG. 92.—Diagram of Miller's winding showing three sections.

from a single section to give the required spark to a coil consisting of ten or more subdivided sections wound full of wire; the logical sequence would be to wind a very large number of sections, each section containing only one spiral or wire regularly.

This is in effect Miller's arrangement of winding, and Fig. 92 shows three sections with the paper discs opened out for clearness with the single wire spirals affixed to the paper. Actually, of course, these paper discs are strongly compressed. The winding is accomplished in the following manner. The waxed paper disc

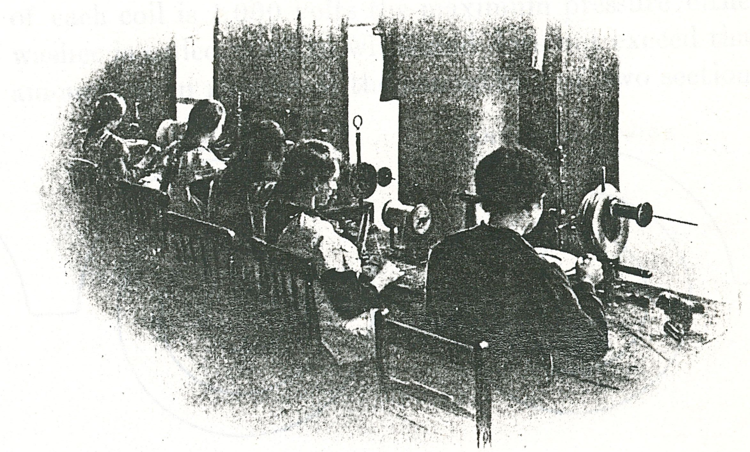


FIG. 93.—Photo of Miller's sections being wound.

FIG. 94.—Photo of Miller's sections being assembled in blocks.

to be wound is affixed to a table rotating after the manner of a gramophone and the wire applied by a wire feed arrangement which first ploughs a small furrow in the wax for the wire to lie in and then rolls it down with a roller. The wire feed apparatus is caused to traverse the rotating table diametrically by a screw thread similar to the leading screw of a lathe, the consequence is that the wire is applied to the waxed paper washer in exactly the form of the thread on a gramophone record. In order to avoid cutting the wire at the beginning and end of each section the paper discs are ingeniously fed into place over the whole bobbin of wire and the wire feed, thereby enabling the coil to be made jointlessly (Fig. 93). Mr. Miller states there are about 1,000 of these sections connected in series in a 16″ coil, the whole being compressed into solid blocks (Fig. 94) and assembled on the primary tube.

It will be noticed in all the section coils dealt with that the connections have been assumed to have been made symmetrically, that is, the two adjacent inner ends and outer ends have been connected together in the manner shown in Fig. 95, but wound in opposite directions, viz. 1, 3, 5, 7, 9 clockwise and 2, 4, 6, 8, 10 anti-clockwise. If, for argument, each section gives 1,000 volts pressure, the total pressure of the two sections as before explained will equal 2,000 volts and the insulating washer between the sections must be capable of withstanding that pressure.

There is, however, another method of connecting the sections as shown in Fig. 96 in which the inner end of one section is connected to the outer end of the next, all sections being wound in the *same* direction. It will immediately be noticed that we have now a wire traversing the windings of both sections and that it will be necessary to interpose an insulating washer on each side of this conductor, in other words two washers

instead of one must be used. As, however, the pressure of each coil is 1,000 volts the maximum pressure either washer is called upon to withstand does not exceed that amount, as in no part of the assembling of two sections

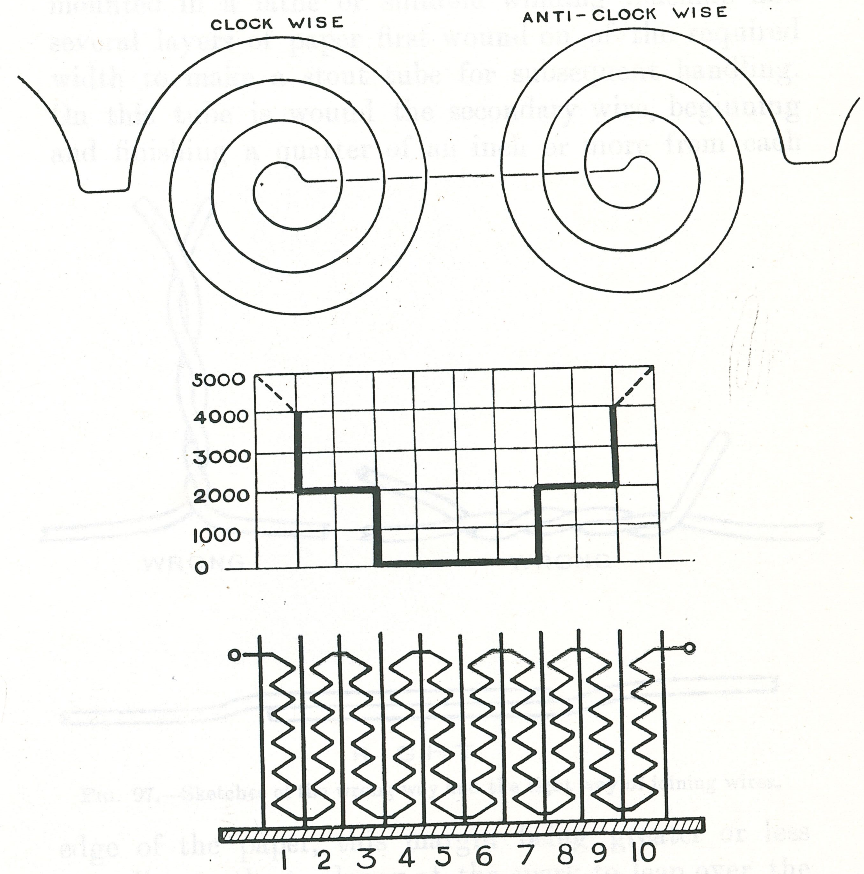


FIG. 95.—Diagram of sections wound with different rotations.

so connected does a voltage greater than 1,000 occur, therefore each of the two insulating washers need only be half as thick as the single washer in the previously considered method of connection, there is so far, therefore, no particular advantage in either of these two methods. Reverting to Fig. 95, we see that each time

the secondary approaches the primary tube its pressure has increased 2,000 volts or the sum of the pressures of two sections, whereas in Fig. 96 each time the wire approaches the tube the potential has only risen 1,000 volts, or the pressure of one section, that is the potential gradient along the tube, though practically alike in the

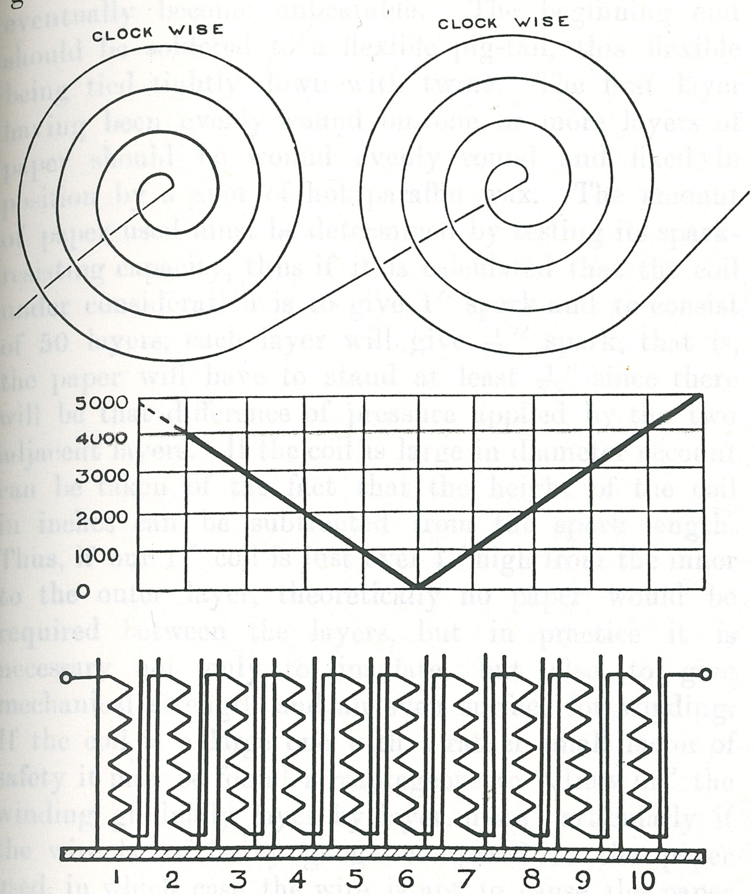


FIG. 96.—Diagram of sections wound all in one direction.

end in both methods of connection, is more regular in the second method and less likely to make isolated nodes of high pressure than in the former, and this supposition appears to be confirmed in practice.

METHODS OF MANUFACTURE.

Layer Windings.

In order to make a layer winding a mandrel is mounted in a lathe or suitable winding machine and several layers of paper first wound on of the required width to make a stout tube for subsequent handling. On this tube is wound the secondary wire, beginning and finishing a quarter of an inch or more from each

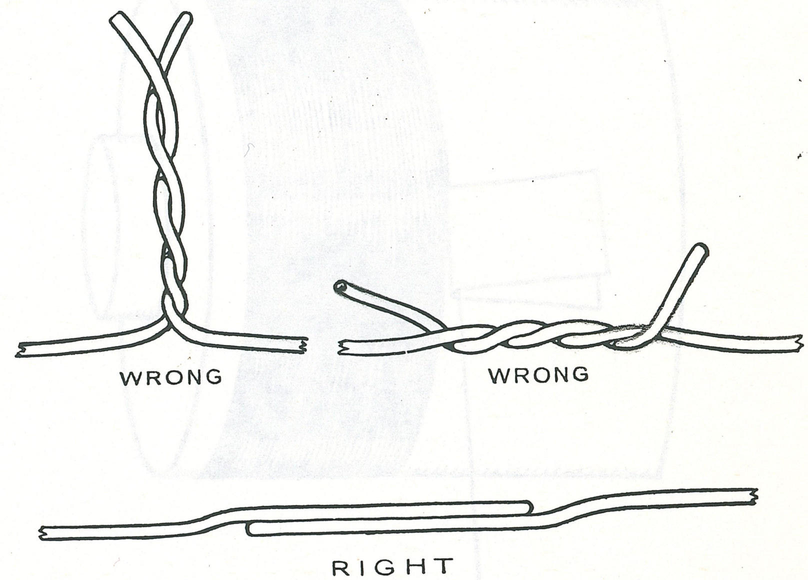


FIG. 97.—Sketches of the wrong way and the right way of joining wires.

edge of the paper, this margin being greater or less according to the tendency of the spark to leap over the edges, as explained on p. 92. The layers can best be wound by hand, but machines are sometimes employed, especially in small cheap coils where bare wire is sometimes used space wound so that each succeeding turn is separated from its neighbours by a small space to prevent touching. Machine wound coils are, however, very prone to break down because the strain applied by

the wire feed is not so sensitive as when applied by hand and the cumulative strain of succeeding turns and layers eventually presses the underlying turns together, causing a burn out. The effect is analogous to winding cotton in many turns round the finger. However light the tension may be, the pressure will eventually become unbearable. The beginning end should be soldered to a flexible pig-tail, this flexible being tied tightly down with twine. The first layer having been evenly wound on, one or more layers of paper should be wound evenly round and fixed in position by a spot of hot paraffin wax. The amount of paper used must be determined by testing its spark-resisting capacity, thus if it is calculated that the coil under consideration is to give 1″ spark and to consist of 50 layers, each layer will give $\frac{1}{50}$″ spark, that is, the paper will have to stand at least $\frac{1}{25}$″ since there will be that difference of pressure applied by the two adjacent layers. If the coil is large in diameter account can be taken of the fact that the height of the coil in inches can be subtracted from the spark length. Thus, if our 1″ coil is just over 1″ high from the inner to the outer layer, theoretically no paper would be required between the layers, but in practice it is necessary not only to insulate, but also to give mechanical strength and an even surface for winding. If the coil is a large one with a rather small factor of safety it may be found advantageous to "draw in" the winding gradually layer by layer, more particularly if the wire be of heavy gauge compared to the paper used, in which case the wire is apt to cause the paper to collapse and the outer turns to slip down. When all the turns have been applied the finishing pig-tail should be soldered on and tied down lightly with twine, care being taken that the soldered joint is not pressed into the paper by the pressure of the twine. A word may

be said here about joining secondary wires. Firstly, the ends should be bared by rubbing lightly with a folded piece of fine emery or glass-paper. The ends should then be laid one on the other overlapping about $\frac{1}{8}$″, and quickly soldered with a small soldering iron, using resin or soldering paste as a flux (Fig. 97). Spirit should not be used, but there is no objection to soldering paste, if the excess be removed with a small piece

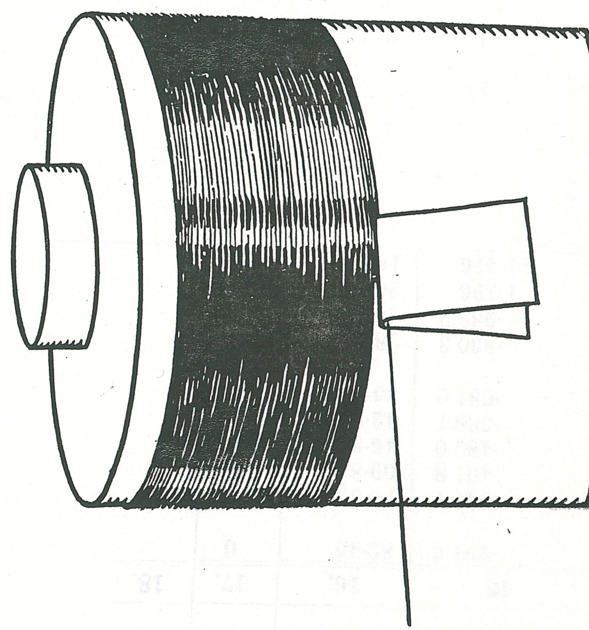


FIG. 98.—Sketch of paper tab folded in to cover joint in secondary wire.

of rag or soft paper. Never twist the ends together, as this leaves a bump in the wire besides tending to set up a strain, which may eventually develop into a fracture of the wire. The join can then be covered by folding over a piece of paper, the tabs being wound in by the succeeding turns (Fig. 98). The completed coil should present a perfectly even surface, true and devoid of bumps and irregularities, moreover no wire

should show at the ends. The coil, if a small one, may next be detached from its mandrel. This can be easily done if in the first place the mandrel be made rather smaller than is required, the difference in diameter being made up by a layer of cord or stout twine according to the size of the coil being wound. In order to free the coil from the mandrel, it is only necessary to pull one end of the cord, which has been temporarily fixed with a spot of wax, when it will unwind, allowing the mandrel easily to be withdrawn. Large coils are usually wound on collapsible, conical, or split mandrels, usually metal, more particularly as the weight of a large coil renders it necessary to retain the mandrel while the coil is treated in the wax tank to avoid collapsing, then when the coil has set, the mandrel may be withdrawn without danger. Coils of this description, if not impregnated in vacuo, should not be withdrawn from the wax till in a semi-solid condition, as the copper retains its heat for a considerable time after the exterior skin of wax has set, and therefore the interior of the coil is liable to have its wax contents drain out to the prejudice of its insulating qualities. The coil or section now being waxed internally, more wax should be applied to the edges of the paper layers and worked in well with a hot iron, till bubbles cease to be expelled. Some makers cast their coils in a mould, this mould being under vacuum or not as their resources and experience may dictate.

In order to arrive at the size of any coil the accompanying table (Plate VI.) will be found of use when constructing layer-wound coils. For example, suppose we desire to construct a coil giving about a 3″ spark, and having 15,000 turns of secondary. Referring to Plate VI., we find in Column 16 that No. 36 carries ·045 amp., or 45 milliamperes, which we will assume is sufficient for our purpose. For a 3″ spark, silk-covered

PLATE VI.

Yards per pound.	Ohms per 1,000 yards.	Current at 1,000 amps. per square inch.	Size S.W.G.	Nearest A.W.G.
14.	15	16.	17.	18.
1·049 6	·291 6	82·45	0	
1·224 3	·340 1	70·69	1	1
1·446 4	·401 8	59·83	2	2
1·735 1	·482 0	49·88	3	
2·047 1	·568 7	42·27	4	3
2·451 6	·681 0	35·30	5	
				4
2·989 0	·830 3	28·95	6	5
3·557 0	·988 2	24·33	7	
4·304 3	1·196	20·11	8	6
5·313 6	1·476	16·29	9	7

WIRE TABLE.

.G.	Diam.	Sectional area in square inches.	Silk Covered.				Cotton Covered.				Enamel.		Ohms per pou
			Single.		Double.		Single.		Double.				
			Diam.	Turns per inch.	Diam.	Turns per inch.	Diam.	Turns per inch.	Diam.	Turns per inch.	Diam.	Turns per inch.	
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
0	·324	·082 45											·000 3
1	·300	·070 69											·000 4
2	·276	·059 83											·000 5
3	·252	·049 88											·000 8
4	·232	·042 27											·001 1
5	·212	·035 30											·001 6
6	·192	·028 95											·002 4
7	·176	·024 33											·003 5
8	·160	·020 11											·005 1
9	·144	·016 29											·007 8
0	·128	·012 87									·131	7·6	·012 5
1	·116	·010 57									·119	8·4	·018 6
2	·104	·008 495	·107	9·3	·108 5	9·2	·112	8·9	·118	8·4	·107	9·3	·028 8
3	·092	·006 648	·095	10·5	·096 5	10·3	·100	10·0	·106	9·4	·095	10·5	·047 0
4	·080	·005 027	·083	12·0	·084 5	11·8	·088	11·3	·094	10·6	·083	12·0	·082 3
5	·072	·004 072	·075	13·3	·076 5	13·0	·079	12·6	·084	11·9	·074 5	13·4	·125 5
6	·064	·003 217	·067	14·9	·068 5	14·5	·071	14·0	·076	13·1	·066 5	15·0	·200 9
7	·056	·002 463	·059	16·9	·060 5	16·5	·063	15·8	·068	14·7	·058 5	17·0	·342 78
8	·048	·001 810	·050	20·0	·051 5	19·4	·054	18·5	·058	17·2	·050 5	19·8	·635 04
9	·040	·001 257	·042	23·8	·043 5	22·9	·046	21·7	·050	20·0	·042 2	23·6	1·316 8
0	·036	·001 018	·038	26·3	·039 5	25·3	·042	23·8	·046	21·7	·038 2	26·1	2·007 0
1	·032	·000 804 2	·034	29·4	·035 5	28·1	·038	26·3	·042	23·8	·034 0	29·4	3·214 9
2	·028	·000 615 8	·030	33·3	·031 5	31·7	·034	29·4	·038	26·3	·030 0	33·3	5·484 5
3	·024	·000 452 4	·026	38·4	·027 5	36·3	·030	33·3	·034	29·4	·025 7	38·9	10·161
4	·022	·000 380 1	·023 75	42·1	·025 0	40·0	·028	35·7	·032	31·2	·023 7	42·1	14·391
5	·020	·000 314 2	·021 75	45·9	·023 0	43·4	·026	38·4	·030 0	33·3	·021 7	46·0	21·069
6	·018	·000 254 5	·019 75	50·6	·021 0	47·6	·024	41·6	·028 0	35·7	·019 7	50·7	32·112
7	·016 4	·000 211 2	·018 15	55·1	·019 4	51·5	·022 4	44·6	·026 4	37·8	·017 9	55·9	46·600
8	·014 8	·000 172 0	·016 55	60·3	·017 8	56·1	·020 8	48·0	·024 8	40·3	·016 3	61·3	70·261
9	·013 6	·000 145 3	·015 35	65·4	·016 6	60·2	·019 6	51·0	·023 6	42·3	·015 1	66·2	98·539
0	·012 4	·000 120 8	·013 9	71·9	·014 9	67·1	·018 4	54·3	·022 4	44·6	·013 6	73·5	142·59
1	·011 6	·000 105 7	·013 1	76·3	·014 1	70·9	·017 6	56·8	·021 6	46·3	·012 8	78·1	186·18
2	·010 8	·000 091 6	·012 3	81·3	·013 3	75·1	·015 8	63·2	·019 8	50·5	·012 0	83·3	247·78
3	·010 0	·000 078 5	·011 5	86·9	·012 5	80·0	·015 0	66·6	·019 0	52·6	·011 2	89·2	337·11
4	·009 2	·000 066 5	·010 7	93·4	·011 7	85·4	·014 2	70·4	·018 2	54·9	·010 2	98·0	470·56
	·008 4	·000 055 4	·009 9	101·0	·010 9	91·7	·012 4	80·0	·016 4	[illegible]	·009 4	106·3	677·09
	·007 6	·000 045 4	·009 1	109·8	·009 8	101·5	·011 6	86·2	·015 6	64·1	·008 6	116·2	1 010·3
	·006 8	·000 036 3	·008 3	120·4	·009 0	110·5	·010 8	92·5	·014 8	67·5	·007 8	128·2	1 576·6
	·006 0	·000 028 2	·007 5	133·3	·008 2	121·2	·010 0	100·0	·014 0	71·4	·007 0	142·8	2 601·1
	·005 2	·000 021 2	·006 7	149·2	·007 4	134·2	·009 2	108·6	·013 2	75·7	·005 9	169·4	4 610·5
	·004 8	·000 018 1	·006 3	158·7	·007 0	141·8	·008 4	119·0	·012 8	78·1	·005 5	181·8	6 350·4
	·004 4	·000 015 2	·005 65	176·9	·006 2	161·2					·005 1	196·0	8 994·0
	·004 0	·000 012 6	·005 25	190·4	·006 0	166·6					·004 7	212·7	13 168·0
	·003 6	·000 010 2	·004 85	206·1	·005 6	178·5					·004 3	232·5	20 071·0
	·003 2	·000 008 0	·004 45	224·7	·005 2	192·3					·003 9	256·4	32 149·0
	·002 8	·000 006 2	·004 05	246·9	·004 8	208·3					·003 3	303·0	54 845·0
	·002 4	·000 004 5	·003 65	273·9	·004 4	227·2					·002 9	344·8	101 609·0
	·002 0	·000 003 1	·003 25	307·6	·004 0	250·0					·002 4	416·6	210 690·0
	·001 6	·000 002 011											514 380·0
	·001 2	·000 001 131											1 625 700·0
	·001 0	·000 000 785 4											3 371 090·0

To face p. 106. Codd, "Induction Coil Design."]

WIRE TABLE.

PLATE VI.

otton Covered.			Enamel.							
	Double.									
Turns per inch.	Diam.	Turns per inch.	Diam.	Turns per inch.	Ohms per pound.	Yards per pound.	Ohms per 1,000 yards.	Current at 1,000 amps. per square inch.	Size S.W.G.	Nearest A.W.G.
8.	9.	10.	11.	12.	13.	14.	15	16.	17.	18.
					·000 305 9	1·049 6	·291 6	82·45	0	
					·000 416 1	1·224 3	·340 1	70·69	1	1
					·000 580 9	1·446 4	·401 8	59·83	2	2
					·000 835 9	1·735 1	·482 0	49·88	3	
					·001 163 6	2·047 1	·568 7	42·27	4	3
					·001 668 8	2·451 6	·681 0	35·30	5	4
					·002 480 6	2·989 0	·830 3	28·95	6	5
					·003 513 3	3·557 0	·988 2	24·33	7	6
					·005 143 8	4·304 3	1·196	20·11	8	
					·007 840	5·313 6	1·476	16·29	9	7
			·131	7·6	·012 558	6·725 3	1·868	12·87	10	8
			·119	8·4	·018 618	8·188 6	2·275	10·57	11	9
8·9	·118	8·4	·107	9·3	·028 816	10·187 3	2·830	8·495	12	10
10·0	·106	9·4	·095	10·5	·047 056	13·018 3	3·616	6·648	13	11
11·3	·094	10·6	·083	12·0	·082 301	17·216 6	4·783	5·027	14	12
12·6	·084	11·9	·074 5	13·4	·125 30	21·255 0	5·905	4·072	15	13
14·0	·076	13·1	·066 5	15·0	·200 93	26·901 0	7·473	3·217	16	15 14
[illegible]	·068	14·7	·058 5	17·0	·342 78	35·136	9·761	2·463	17	16
8·5	·058	17·2	·050 5	19·8	·635 04	47·823	13·29	1·810	18	17
1·7	·050	20·0	·042 2	23·6	1·316 8	68·866	19·13	1·257	19	18
3·8	·046	21·7	·038 2	26·1	2·007 [illegible]	85·020	23·62	1·018	20	19
6·3	·042	23·8	·034 0	29·4	3·214 9	107·603	29·89	·804	21	20 21
9·4	·038	26·3	·030 0	33·3	5·484 5	140·543	39·04	·616	22	22
3·3	·034	29·4	·025 7	38·9	10·161	191·296	53·14	·452	23	
5·7	·032	31·2	·023 7	42·1	14·391	227·66	63·24	·380 1	24	23
8·4	·030 0	33·3	·021 7	46·0	21·069	275·46	76·52	·314 2	25	24
1·6	·028 0	35·7	·019 7	50·7	32·112	340·10	94·47	·254 5	26	25
4·6	·026 4	37·8	·017 9	55·9	46·600	419·66	113·8	·211 2	27	26
8·0	·024 8	40·3	·016 3	61·3	70·261	503·03	139·7	·172 0	28	27
1·0	·023 6	42·3	·015 1	66·2	98·539	595·73	165·5	·145 3	29	28
4·3	·022 4	44·6	·013 6	73·5	142·59	716·60	199·1	·120 8	30	
6·8	·021 6	46·3	·012 8	78·1	186·18	818·86	227·5	·105 7	31	29
3·2	·019 8	50·5	·012 0	83·3	247·78	944·70	262·4	·091 6	32	
6·6	·019 0	52·6	·011 2	89·2	337·11	1 101·86	306·1	·078 5	33	30
0·4	·018 2	54·9	·010 2	98·0	470·56	1 301·83	361·6	·066 5	34	31
0·8	·016 4	60·9	·009 4	106·3	677·09	1 561·60	433·8	·055 4	35	32
6·2	·015 6	64·1	·008 6	116·2	1 010·3	1 907·66	529·9	·045 4	36	33
2·5	·014 8	67·5	·007 8	128·2	1 576·6	2 382·93	662·0	·036 3	37	
0·0	·014 0	71·4	·007 0	142·8	2 601·1	3 060·73	850·3	·028 3	38	34 35
8·6	·013 2	75·7	·005 9	169·4	4 610·5	4 075·0	1 132 0	·021 2	39	36
9·0	·012 8	78·1	·005 5	181·8	6 350·4	4 782·3	1 329·0	·018 1	40	
			·005 1	196·0	8 994·0	5 691·3	1 581·0	·015 2	41	37
			·004 7	212·7	13 168·0	6 886·6	1 913·0	·012 6	42	38
			·004 3	232·5	20 071·0	8 502·0	2 362·0	·010 2	43	39
			·003 9	256·4	32 149·0	10 760·0	2 989·0	·008 0	44	40
			·003 3	303·0	54 845·0	14 054·0	3 904·0	·006 2	45	
			·002 9	344·8	101 609·0	19 129·6	5 314 0	·004 5	46	
			·002 4	416·6	210 690·0	27 546·6	7 652·0	·003 1	47	
					514 380·0	43 043·3	11 957·0	·002 0	48	
					1 625 700·0	76 520·0	21 256·0	·001 1	49	
					3 371 090·0	110 186·6	30 609·0	·000 7	50	

[E. & F. N. Spon, Ltd.

wire should be used, and, since it is a layer wound coil, single silk will suffice. In Column 7 we find No. 36 S.S.C. lies 109·8 turns per inch, allow 10 per cent. for slack winding, and we may count on say 100 turns per inch run. Therefore 15,000 will give us a spiral 150″ long. We have next to divide this by the length of the layers, which in this case we will take as 3″. Therefore the number of layers will be $\frac{150}{3} = 50$ layers. As the coil is to produce a 3″ spark each layer will give $\frac{3}{50}$ of an inch, and the paper layers will thus have to withstand $\frac{6}{50}$ or say $\frac{1}{8}$ of an inch spark. Allowing that experiment has shown that 5 mils of paper is sufficient insulating material between each layer, this thickness must be added to the diameter of the covered wire, ·0091 Column 3 giving a total of wire, silk and paper of ·0141. Multiplying this by 50 layers we get ·705, and as there will be a certain slackness of winding depending on the skill of the operator, but which will be a minimum of 10 per cent., we get ·775 or over $\frac{3}{4}$″.

As the width of winding is 3″, and as each two layers of wire produce $\frac{1}{8}$″ spark the paper must protrude at least $\frac{1}{4}$″ each end, that is, finally, the coil over the paper will be $3\frac{1}{2}$″ wide and rather over $\frac{3}{4}$″ deep. It will at once be seen that some difficulty will be experienced in "bottling up" the spark unless the coil be heavily cast up in wax, which is a proceeding which should only be resorted to when other means of insulation are not allowable. In this case the coil should preferably be wound in two sections of 7,500 turns assembled on a light paper tube; in this manner the risk of breakdown is balked at every point. The above example should not be taken as an actual case, but simply to give an idea as to how the size of any coil may be approximately arrived at.

Section or Spiral Winding.

We next come to the alternative method of section winding in which the secondary wire is wound in a large number of narrow washers or rings separated from one another by insulating partitions. Miller's method of single wire spirals has already been explained, and we will therefore pass on to the more general method, which, with variations depending on the ideas of the manufacturer, is as follows:—Two flat circular discs A, B (Fig. 99) of the required diameter are separated by a third smaller disc C, the whole being held together by the shouldered mandrel D and the lock nut E. The winding spool or bobbin so formed is mounted in a lathe or between centres so that it can be rotated at a fair speed. G represents a small hole for the inner end of the wire to emerge from. The disc C serves not only to fix the inner diameter of the section but also the distance between the discs A and B.

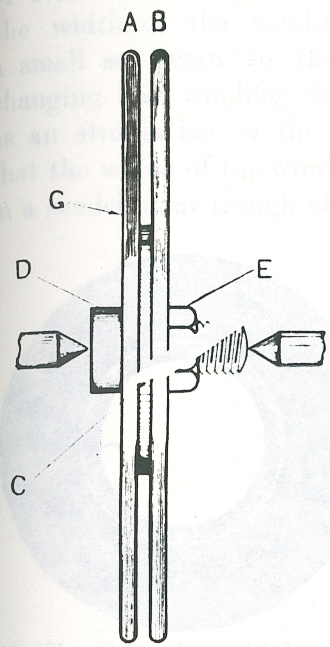


Fig. 99.—Diagram of section winder.

This distance varies with the size of the coil and the length of the spark each section will be called upon to give, together with the quality of the insulation on the secondary wire. Generally speaking, the width of these sections for a 12″ coil with single or double silk-covered wire would be $\frac{3}{32}$″, and about 100 would be needed, giving a total length of wire of $9\frac{3}{8}$″, to which must be added

the thickness of a similar number of insulating partitions. Besides the winding discs above described certain other apparatus will be needed (Fig. 100). Here A represents the winding discs set up to rotate in the winding lathe, B is a flat metal dish containing hot paraffin wax kept hot by a small burner beneath. In the centre of the dish at the bottom is soldered a metal hook C through which the wire passes from the spool of wire D. After leaving the hook the wire should pass through a wiper E, located just inside the dish so that surplus wax removed by the wiper may flow back and avoid waste.

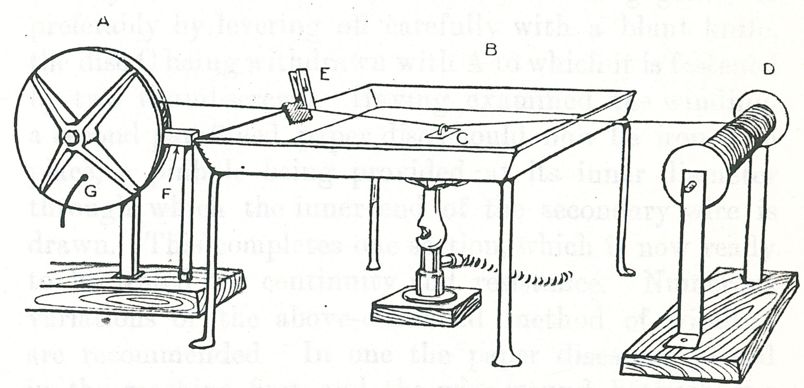


Fig. 100.—Sketch of section winding apparatus.

The wiper itself can be made of a piece of folded felt or thick flannel held by a metal spring clip or the like so as to keep a gentle pressure on the wire. The spool D is mounted on a rough stand with two uprights and a length of rod thrust through to form a spindle. The writer has not found much trouble occur with unwinding of the wire by the momentum of the bobbin, if reasonable care be exercised, though, doubtless, some form of brake could be contrived similar to that shown on p. 115, but generally any strain on the wire is to be avoided, as it is much magnified by the friction of passing through the bath B, and for this reason the

edges of the tins and wherever else the wire touches should be carefully rounded. This applies equally to the edges of the winder discs A and it will be found advantageous to fix a small scraper F between the discs to remove the frost-like deposit of cold wax which forms there and in time tends to catch up and jerk the wire, forming undesirable loops and chords, as already described. The scraper itself should be a small piece of steel or metal about $\frac{3}{4}''$ high by rather less than the width of the winding groove, held in place by a small set screw so that it is easily removable for changing the winding discs. It has been suggested, as an alternative to the apparatus already described, that the whole of the winding discs should be submerged in a semicircular trough of melted wax. The writer has not tried this method, as it seems to him a quantity of wax would be thrown off by centrifugal force and thus create considerable waste and mess besides rendering the running of the apparatus sluggish. The idea is, however, given for the sake of completeness and as a suggestion for experiment. The above apparatus being set up, it only remains to pass the end of the secondary wire through the wax bath and on to the winder, the end being threaded through a small hole G near the inner diameter of the disc left for this purpose. The winding machine can now be turned at a fair speed till the desired number of turns have been laid on. For this purpose it is desirable to have a rev. counter

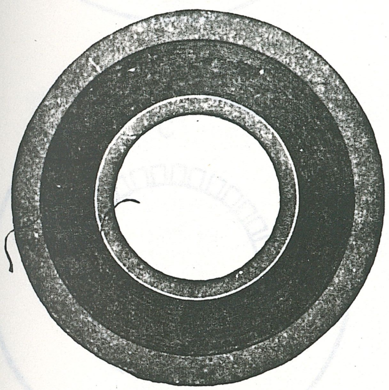


FIG. 101.—Photo of completed section on paper washer with interior cardboard ring.

geared to the lathe in any suitable manner. The wire now being wound into place the outer end should be fixed with a drop of wax, the nut E unscrewed and the plate B cautiously removed. A complete ring of wire should now be visible, free from chords or other irregularities (Fig. 101). A disc of paraffin wax paper should now be taken, rather larger in external diameter than the finished section of wire and rather less in internal diameter, and laid on the ring of wire, to which it can be caused to adhere by warming gently with a hot flat iron. Thus strengthened, the second disc A may now be detached, either by warming gently or preferably by levering off carefully with a blunt knife, the disc C being withdrawn with A to which it is fastened by two thumbscrews. Having examined the winding, a second paraffined paper disc should now be ironed in place, a pinhole being provided at its inner diameter through which the inner end of the secondary wire is drawn. This completes one section, which is now ready to be tested for continuity and resistance. Numerous variations of the above-described method of winding are recommended. In one the paper discs are placed in the machine first and the wire wound between the papers instead of applying them after. The writer has found this method unsatisfactory in that the wax tends to set on the papers at the diameter in exactly the way the scraper is there to prevent, resulting in uneven winding of the wire. In another method the paper discs are fixed together before being wound, one disc being a plain washer A (Fig. 102), the other having tabs joined at its inner diameter B. The two washers are now placed side by side and the tabs folded over the plain washer A and fixed in position by paste or other suitable means, as shown at C. This arrangement is now placed in the machine and the wire wound on. Two sections of this description are assembled

together, one being wound right- and one left-handedly, respectively. The inner ends being soldered together, the inner diameter of the pair is embraced by a cartridge paper ring formed gutter shape, as shown at D in section. The gutter, or V-shaped section, is obtained by passing strips of cartridge paper between a groove

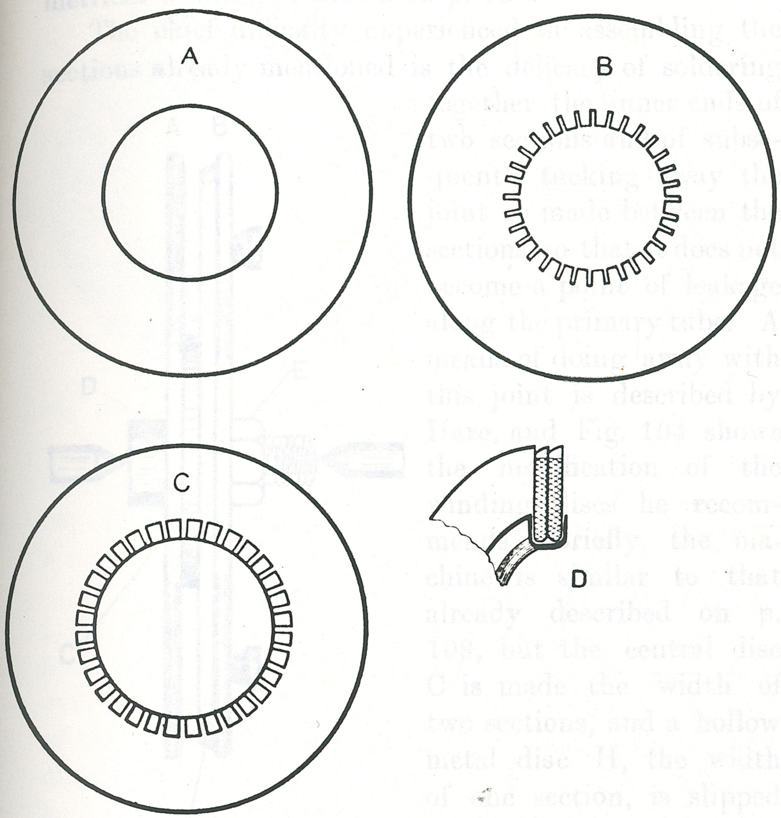


FIG. 102.—Paper washers for twin sections.

of the required shape in a wooden bobbin and a tightly stretched cord. The bobbin is moved to and fro with the cord round its waist. The paper trapped between is thus gradually brought to the required shape as the cord is tightened.

Some manufacturers, in order to reinforce the primary

tube at the ends where the pressure is greatest, increase the internal diameter of the sections. This may be accomplished either by gradually increasing the size of the disc C, or by winding on an increasing quantity of waxed cotton before beginning to apply the wire. Another method is to apply rings of cardboard, or other suitable material, to the centre disc, and wind on that, as shown in Fig. 101.

In the event of a larger bore being required for the sections as they near the ends of the coil, it will be necessary to change the disc C for one of increasing

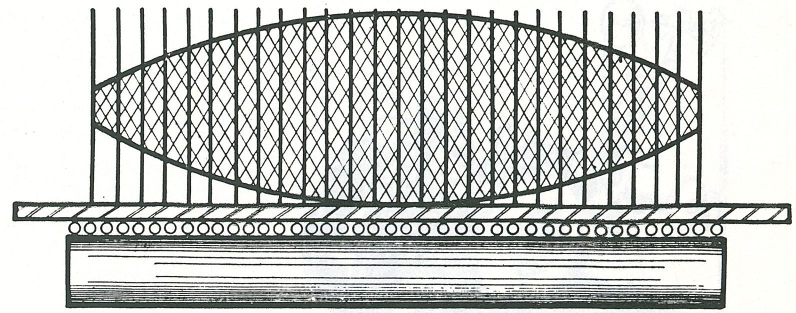


FIG. 103.—Section of coil with graded drop sections.

diameter to accommodate the increasing bore, and, for that reason, the before-mentioned thumbscrews are necessary to fix the large disc A to the small disc C. Fig. 103 shows a secondary wound as described, the bore gradually increasing from the centre at zero pressure symmetrically to the ends where maximum pressure exists. Some makers, reasoning that the leakage of magnetic lines is greatest at the ends, diminish the number of turns also at the outer diameter of succeeding sections, such sections being known as "drop sections," the general effect of this diminution of winding both at the interior and exterior diameters is a cigar-shaped section as shown. In the writer's opinion the diminution of the inner diameter shows a want of faith in the insulating qualities of the primary tube employed, while

the diminution of the outer turns seems hardly worth while, as if drop sections must be employed the core is either badly designed, or the turns might be more usefully employed elsewhere. The net result for practical purposes should be a perfectly cylindrical and symmetrical winding as shown on p. 120.

The chief difficulty experienced in assembling the sections already mentioned is the delicacy of soldering together the inner ends of two sections and of subsequently tucking away the joint so made between the sections, so that it does not become a point of leakage along the primary tube. A means of doing away with this joint is described by Hare, and Fig. 104 shows the modification of the winding discs he recommends. Briefly, the machine is similar to that already described on p. 108, but the central disc C is made the width of two sections, and a hollow metal disc H, the width of one section, is slipped over C and screwed tightly to B by thumbscrews. The space between A and H is then wound full of wire in the usual way, after which H and B are removed, and the waxed paper partition ironed to the side of the completed section. The inner end is now joined to the spool of wire and B is replaced *without* the plate H and the second section is wound in

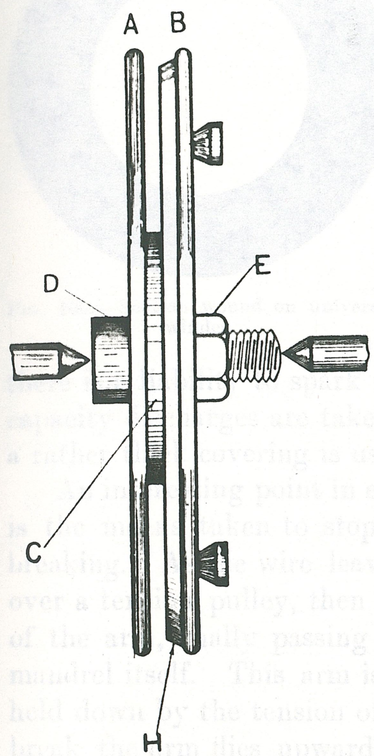


FIG. 104.—Hare's twin section winder.

the space previously occupied by H, the machine being of course turned in the opposite direction. By this means the joint is wound in snugly at the bottom and the two sections can be drawn off the machine as a completed pair.

Another way of winding sections is to use a Universal winder (Fig. 105). This is a machine having the usual rotating mandrel, but the wire feed-motion is geared to the mandrel through a train of gearing and a cam which

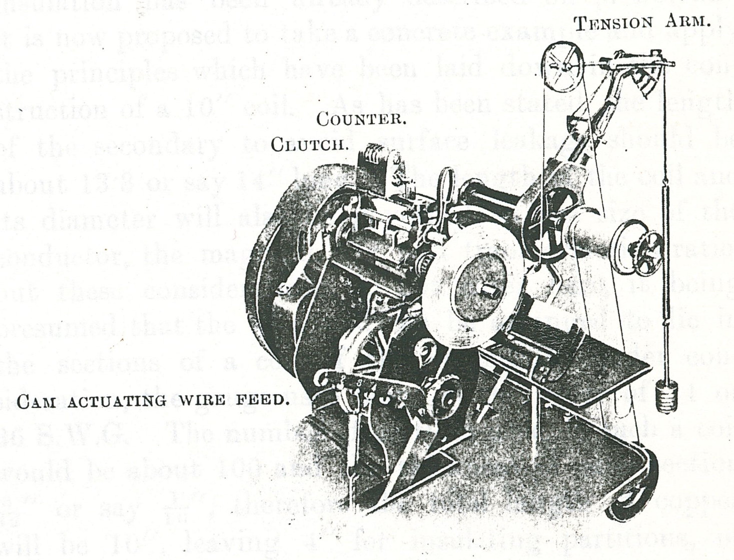


FIG. 105.—Universal winding machine, with wire feed and its cam, bottom spindle with brake wheel, and revolution counter (on top), also weighted tension arm.

gives a throw to the feed mechanism equal to the maximum width of the section required. This throw can be arranged to take place by altering the gearing one or more times for each revolution of the mandrel. In the section shown in Fig. 106, there are five throws or waves per revolution. These waves cross from side to side thereby knitting the whole strongly together and rendering the use of flanges or discs unnecessary. In

order that the cross over of the waves should not always take place in the same diameter, which would cause heaping of the wire at one spot a gainer wheel is arranged in the train of gearing, so that at each revolution of the mandrel the waves or cross-over points advance a small fraction on the preceding ones. In this way nodes are formed and are clearly visible at the sides of the section in a very beautiful manner.

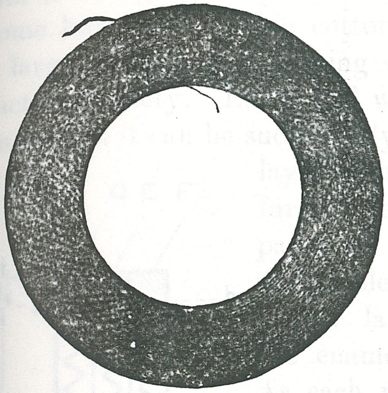


FIG. 106.—Section wound on universal winder.

The great danger of this method of winding is that the wires cross one another so frequently, instead of lying side by side as in other methods of winding, that there is a liability to spark through the covering when capacity discharges are taken from the secondary unless a rather thick covering is used for the wire.

An interesting point in connection with this machine is the means taken to stop it in the event of the wire breaking. As the wire leaves the spool it passes down over a tension pulley, then over the pulley at the end of the arm, finally passing under the wire feed to the mandrel itself. This arm is weighted, but is nominally held down by the tension of the wire. Should the wire break the arm flies upwards, owing to the weight, and this movement trips a mechanism which throws the driving clutch out of action, thereby stopping the mandrel. The spindle that carries the spool of wire is fitted with a pulley having a brake arranged at its periphery. Should the spool tend to overwind itself the wire running off too quickly allows the before-mentioned

arm to rise and thus apply the brake to the spool pulley, checking its further motion. Another refinement is the counter which can be set at a predetermined number of turns. When the correct number has been wound the counter trips the clutch mechanism and stops the machine.

Having determined the method of winding to be employed the question of insulation and the number of sections should now be worked out. The method of insulation has been already described on p. 96, and it is now proposed to take a concrete example and apply the principles which have been laid down in the construction of a 10″ coil. As has been stated, the length of the secondary to avoid surface leakage should be about 13·3 or say 14″ long. The length of the coil and its diameter will also be governed by the size of the conductor, the magnetic flux, and transformation ratio, but these considerations do not enter here, it being presumed that the wire used can be arranged to lie in the sections of a coil of the dimensions under consideration, the gauge used being of the order of 34 or 36 S.W.G. The number of sections used in such a coil would be about 100 and the thickness of each section $\frac{3}{32}''$ or say $\frac{1}{10}''$, therefore the total length of copper will be 10″, leaving 4″ for insulating partitions, of which 101 will be required, giving a thickness of $\frac{1}{25}$ or 40 mils per partition, which should be amply thick, since when each section gives $\frac{1}{10}''$ spark, any adjacent pair will only give $\frac{1}{5}''$, which should not pierce 40 mils of well-insulated paper. We may therefore consider the coil sufficiently well insulated longitudinally, since each section is well insulated from its neighbours and the length of the coil grows more than proportionately to the spark length; as 1·33 to 1. It now remains to examine the question of insulation radially. As each section gives a maximum length of

spark of $\frac{1}{10}''$, the height of the section from the first to the last turn must very considerably exceed this. In practice the height would be about 2″, and although that would in itself seem sufficient insulation, even were the wire very slightly covered, it is better to use double silk if the gauge of wire allows, or even cotton. In some large coils double cotton even is used to absorb a large amount of insulating wax and to give a large factor of safety. Enamelled wire should never be used, as though it can be successfully employed in the smaller layer wound coils, where it is further reinforced by a layer of paper, its covering renders it quite unsuitable for the larger coils (either layer or section) in that the enamel will not absorb wax. As each pair of sections can give $\frac{1}{5}''$ spark it is essential that the edges of the partitions internally and externally should project beyond the windings for a distance well in excess of this, say $\frac{1}{4}''$ at least. Fig. 107 gives an idea of the dimensions we have now obtained and should be compared with Fig. 90 from which the above example is derived. Here, as before, X, Y represent the washer-shaped partitions and a, b the windings. A, B, C represent the inner rings of cardboard or cotton which allow the internal projections of the partition to extend $\frac{1}{4}''$ and D, E, F represent the casing of wax, or waxed cotton, or the like, which is applied on the outside to allow the projection of the partitions externally $\frac{1}{4}''$ to prevent the spark jumping over. These considerations now complete the insulation of the coil both radially and longitudinally, and if correctly worked

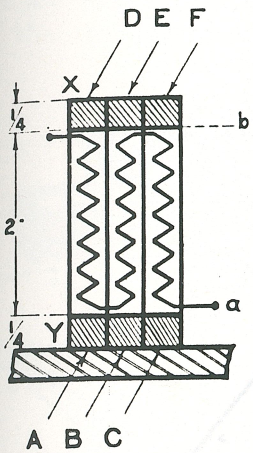


FIG. 107.—Diagram of insulation of detail sections.

out and carefully applied the coil can be pronounced ready for assembly.

ASSEMBLING THE COIL.

This can most conveniently be done by using a stool (Fig. 108) having a slot to accommodate the primary tube and of such height as to reach conveniently to the correct position on the tube where the first secondary section begins. Final adjustment of the tube can be arranged by placing wooden wedges between the end of the tube and the base of the stool. Care should be taken that the tube is at right angles to the plane of the stool top. The first pair of sections should now be laid in place and the space between the primary and the tube should be filled with paraffin or other wax applied from a hot spoon and then worked in well with a small iron (similar to a soldering iron), heated as hot as can be conveniently used without burning the wax and causing it to take fire. A second pair of sections should now be laid on, and the process repeated, the object being to fill all the small interstices between the tube and the secondary, so as to exclude air and moisture. In a similar manner the entire number of sections must be built up. Care should be taken when doing the above to see that the outside ends which remain to be connected do not all come close together in a straight line; it is better to space them out to form a rough spiral as indicated by the dots in Fig. 108; this avoids all chance of sparking over from the exterior soldered joints. If the primary tube be of micanite no special treatment of the tube is necessary, but if ebonite is used it is more satisfactory to roughen the surface of the ebonite with a coarse file and then bind it tightly with thread or tape, which should afterwards be soaked in paraffin wax along that part of its length where the secondary is located.

This applies also to glass or porcelain, except, of course, that the surface need not be roughened. The secondary having now reached this state of completion, it only remains to solder the outer connections as

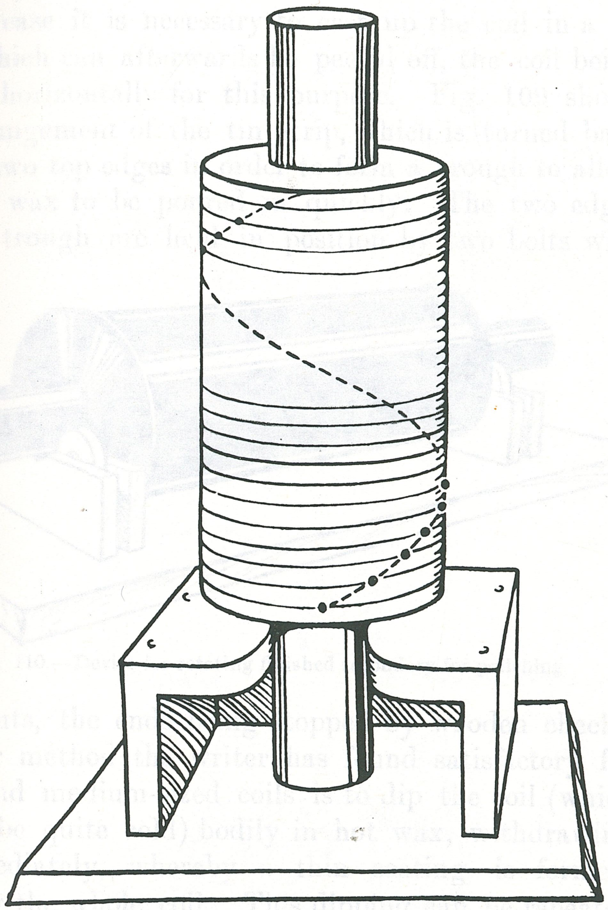


FIG. 108.—Sketch of coil assembling stool.

indicated, and to cast the coil up. The most satisfactory plan of accomplishing this is to use a secondary tube rather longer than the secondary and also $\frac{1}{2}''$ or more greater in diameter. The secondary should now be removed momentarily from its stool, and an ebonite

cheek placed in position against the lower secondary section and then replaced on the stool. The cheek has turned in its inside face a groove to accommodate the edge of the ebonite secondary tube, which should now be placed in position, and hot wax poured in quickly from the top. If the tube is not a good fit in the groove of the cheek the wax will escape, and it may be found necessary to arrange a gasket of string to make a wax-tight joint. The wax, when poured in, will tend to settle down, and care should be taken to see that the

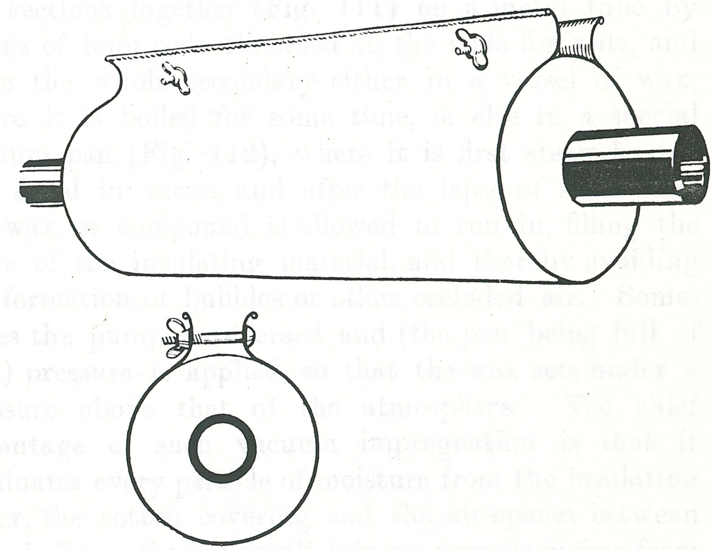


FIG. 109.—Secondary casting-in trough.

tube is full to the brim, then, before the wax begins to set, the second cheek can be placed in position on the top, thereby ensuring that the primary and secondary tubes shall be quite concentric. The ends of the secondary are lead out through flexible tails to binding-screws in the secondary tube, so that the placing in position of the two cheeks does not interfere with the connections. Some makers use dummy cheeks of paraffined wood to support sockets for discharger rods,

in place of terminal screws; the secondary tube being lengthened to accommodate these dummy cheeks.

In some of the cheaper coils the secondary tube is replaced by a thin sheet of ebonite bent round the secondary and laced at the bottom with silk thread. In this case it is necessary to cast up the coil in a tin case, which can afterwards be peeled off, the coil being placed horizontally for this purpose. Fig. 109 shows the arrangement of the tin strip, which is turned back at the two top edges in order to form a trough to allow the hot wax to be poured in quickly. The two edges of the trough are held in position by two bolts with

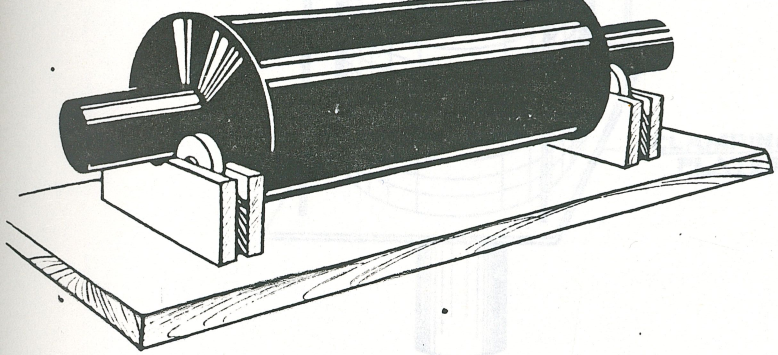


Fig. 110.—Device for rotating finished secondary for polishing.

wing nuts, the ends being stopped by wooden cheeks. Another method the writer has found satisfactory for small and medium-sized coils is to dip the coil (which should be quite cold) bodily in hot wax, withdrawing it immediately, whereby a thin coating is formed, covering the whole coil. This dipping can be repeated till the desired thickness of coating is obtained. The coil should then be trimmed up with a warm spatula till truly cylindrical, care being taken that no blow-holes exist to permit leakage.

In order to rotate the coil conveniently for this purpose, or for polishing the ebonite secondary tube,

etc., the contrivance shown in Fig. 110 is useful. It consists of a board fitted with two uprights, carrying at the top two pulleys of wood or metal so placed as to accommodate the primary tube, and thereby enable the secondary to be turned by hand more conveniently than by placing it in the lathe.

The weak point of all coils so constructed is the tendency to leakage along the primary tube through the inner insulating rings A, B, C, and, therefore, some coil manufacturers, after the coil is assembled, clamp the sections together (Fig. 111) on a metal tube by means of long rods threaded at the ends for nuts, and place the whole secondary either in a vessel of wax, where it is boiled for some time, or else in a special vacuum pan (Fig. 112), where it is first steam-heated and dried in vacuo, and after the lapse of some time hot wax or compound is allowed to run in, filling the pores of the insulating material, and thereby avoiding the formation of bubbles or other occluded air. Sometimes the pump is reversed and (the pan being full of wax) pressure is applied, so that the wax sets under a pressure above that of the atmosphere. The chief advantage of such vacuum impregnation is that it eliminates every particle of moisture from the insulating paper, the cotton covering and the air-spaces between the windings, the net result being a secondary free from air and dampness and constituted of a solid block of wax-insulated copper wire.

Other Methods of Winding.

An interesting method of insulating the secondary is due to Klingelfuss, a maker who has built some of the most powerful coils known.

The means of insulation consist in using a series of recessed or dished washers, the recesses being of varying and increasing diameter, accommodating a few turns of

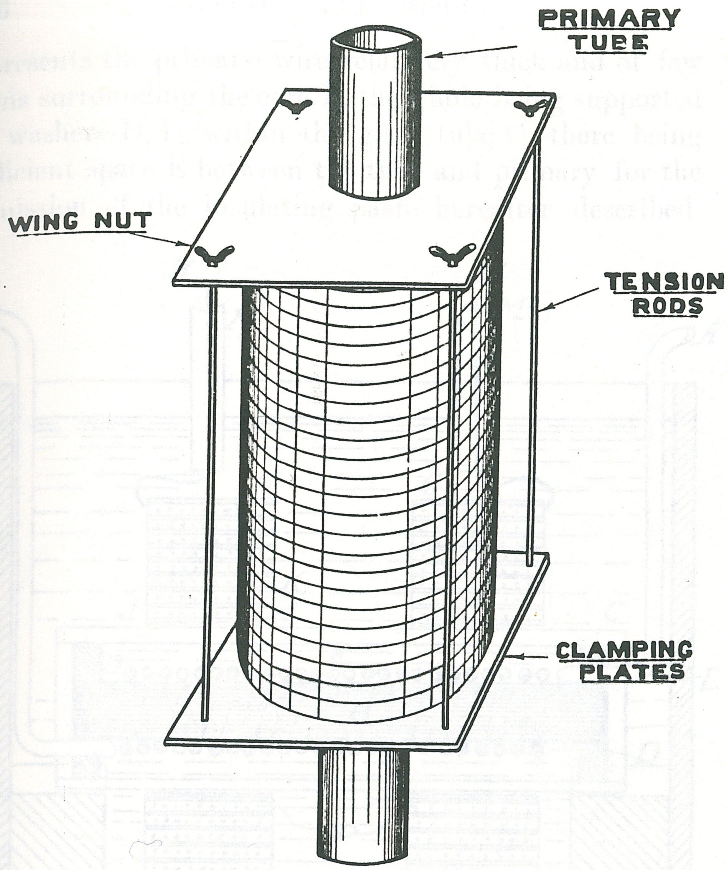


Fig. 111.—Apparatus for compressing sections when assembled.

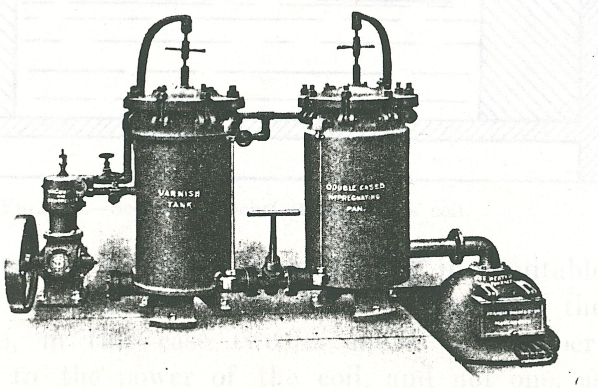


Fig. 112.—Vacuum impregnating apparatus, showing vacuum pan, compound tank, heating stove and vacuum pump.

wire only, wound one-deep between each recess (Fig. 113). Here J1, 2, 3, 4, 5, 6 represent the recessed washers of ebonite, cardboard, or other suitable material, each recess containing in the diagram three turns of wire, and, as there are four compartments in all, there will be twelve turns to a series. The result is that the wire starting

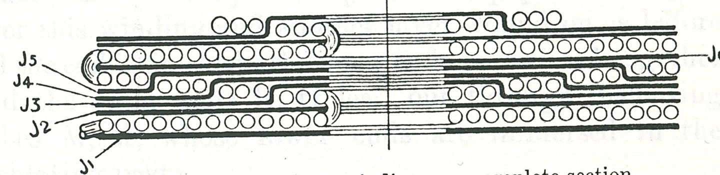


Fig. 113.—Klingelfuss' winding, one complete section.

at the inner turn finds itself, on passing through four succeeding compartments, at the outside, and, to regain the centre, descends in a series of twelve plain turns similar to Miller's winding, to the centre, where the process is repeated. The net result of this series of insulating washers is to interpose a triangular-shaped wedge of insulating material between the points of highest potential, as shown diagrammatically in Fig. 114.

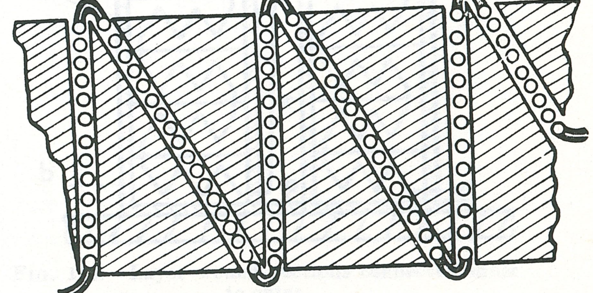


Fig. 114.—Klingelfuss' winding, shown diagrammatically.

The writer has seen sparks over a metre long produced by coils so wound.

Another system of winding, due to Rochefort and Wydts, is shown diagrammatically in Fig. 115. Here A

represents the primary wire relatively thick and of few turns surrounding the core B, the whole being supported by washers D, D, within the glass tube C, there being sufficient space E between the tube and primary for the admission of the insulating paste hereafter described.

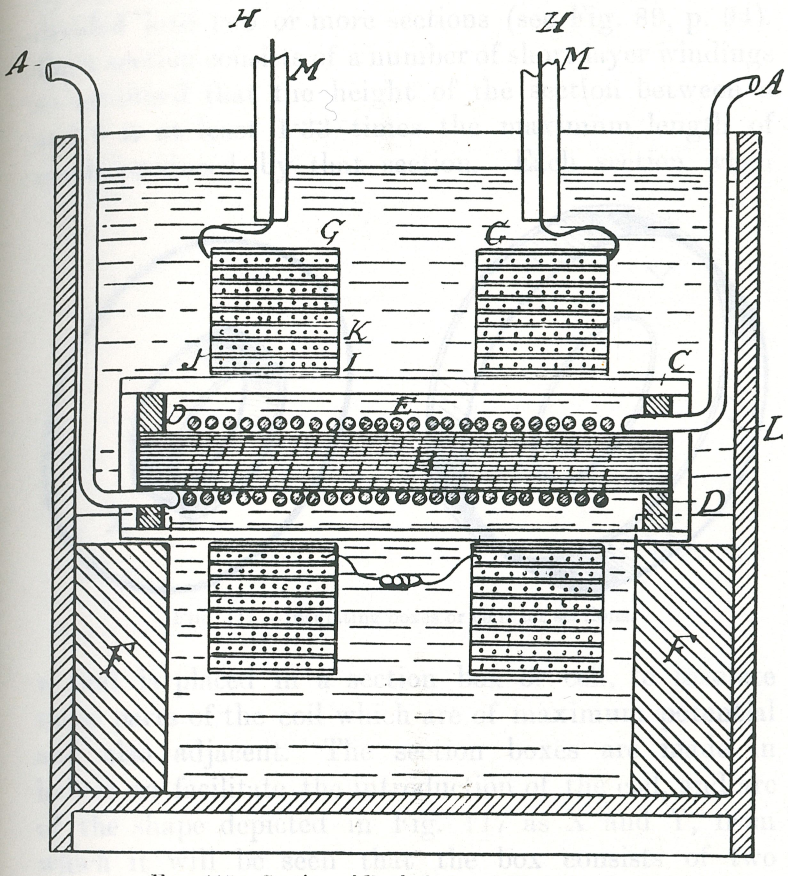


FIG. 115.—Section of Rochefort and Wydts' coil.

The glass tube is supported by crutches F in a suitable receptacle L. On the tube C are supported the secondaries, in this case two or more in number, according to the power of the coil, and not one, as mentioned previously on p. 93. These secondaries

G, G are described as being made as follows: First, a tube is constructed of five or six turns of carefully paraffined paper to make the coil handleable. On this tube is wound the secondary wire I, J in layer form, each turn being separated from its neighbours by a small space in order that the insulating paste may be able to penetrate. Two layers of paraffined paper K are laid over this winding and another layer wound on as before till the coil is finished; the inner ends are twisted together and the outer ends H, H lead out through insulating tubes M, M, whose lower ends are immersed in the insulating paste.

This paste appears to be prepared by dissolving paraffin wax in hot paraffin oil and then immersing the

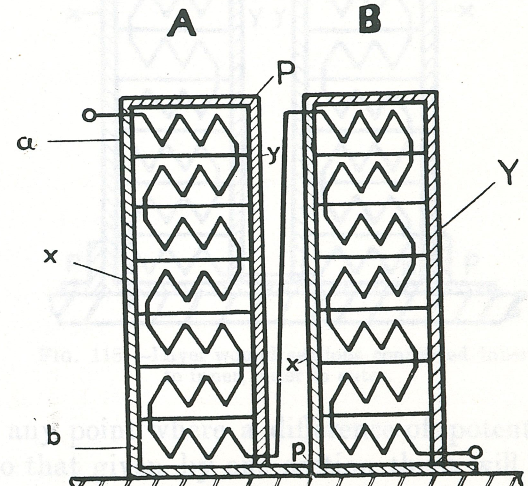


FIG. 116.—Layer wound sections connected inner to outer.

secondaries in the solution for 24 hours to allow the mixture to penetrate. Doubtless this is facilitated when it is remembered the coils have already been wound on paraffined paper which would easily absorb the hot paraffin mixture. At the end of the time mentioned the

mixture is allowed to set, and is claimed to form a very perfect insulation which it is impossible to break down. It will be seen that this is a layer winding and not a section winding proper, although of two sections.

Fig. 116 represents a layer section winding devised by the writer, that is a coil wound in layers but subdivided into two or more sections (see Fig. 89, p. 94). Each section consists of a number of short layer windings so arranged that the height of the section between a and b is at least 1·33 times the maximum length of spark produced by that section. Each section when

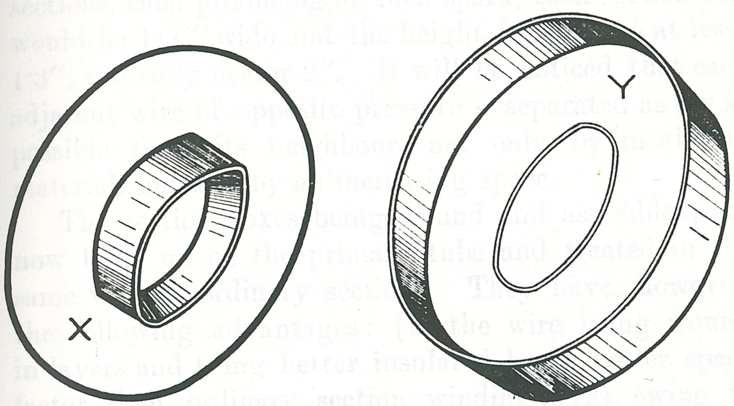


FIG. 117.—Insulating boxes or cells for sections.

wound is placed in a section box or cell, to insulate those parts of the coil which are of maximum potential and also adjacent. The section boxes are made in halves to facilitate the introduction of the coil, and are of the shape depicted in Fig. 117 as X and Y, from which it will be seen that the box consists of two cheeks, the left-hand one X having a tube affixed to its inner diameter or bore, and the right-hand cheek Y also having a tube arranged at its outer diameter.

The result is that when the two parts X and Y are assembled a circular washer-shaped box results which contains the layer wound secondary. These boxes may

be constructed of ebonite, micanite, impregnated cardboard or the like and when assembled are mechanically strong and easily handleable. Fig. 116 shows two such sections A, B, connected up as shown in Fig. 96 that is the inner end of one section connects to the outer end of the next, which is also wound in the same direction. The result, as explained, is to halve the potential of the two sections at any one point. Nevertheless, by virtue of the construction of the section boxes, it will be found

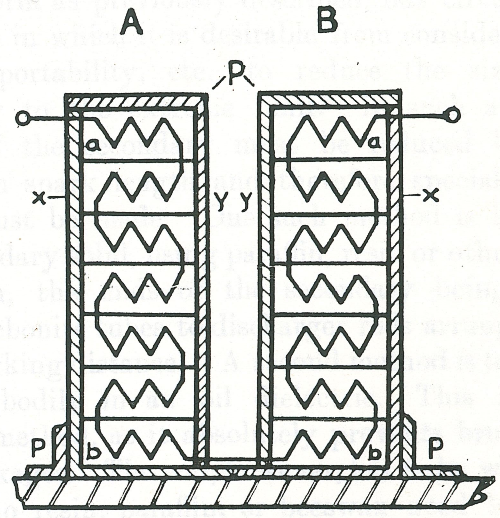


FIG. 118.—Layer wound sections connected inner to inner, outer to outer.

that at any point where a difference of potential exists equal to that given by one section there will also be a full thickness of insulating material, for instance at the points P, P. Fig. 118 illustrates an alternative method of connecting up (similar to that in Fig. 95) in which the sections are connected together at the inner and outer pairs respectively, each pair of coils being wound in different directions.

Here the pair of sections A and B are assembled in the reverse direction to that previously shown and the

sum of the pressures will be adjacent, as at P; but here we find a double thickness of insulation to meet the doubled electrical stresses. This second arrangement, though symmetrical and convenient, is not so satisfactory as the first for very high pressures, owing to the more irregular potential gradient, as explained on p. 102. The width of the section boxes A, B is arranged to be 1·3 times the length of spark produced, so that when the total number is assembled the length of secondary is 1·3 times the spark length. Thus in a 10″ coil of ten sections, each producing an inch spark, each section box would be 1·3″ wide and the height from *a* to *b* at least 1·3″, probably nearer 2″. It will be noticed that each adjacent wire of opposite pressure is separated as far as possible from its neighbour, not only by insulating material, but also by an increasing space.

The section boxes being wound and assembled, are now built up on the primary tube and treated in the same way as ordinary sections. They have, however, the following advantages: (1) the wire being wound in layers and being better insulated has a better space factor than ordinary section winding; (2) owing to the insulating properties of the section box the secondary wire can be wound nearer the primary tube and core than in ordinary section windings; (3) the inner tube of the section box reinforces the primary tube thereby increasing the insulation; (4) the section boxes are mechanically strong and will stand considerable ill use before the winding itself is damaged. Finally, in the manufacture of secondaries it should be borne in mind there are three methods of insulating the windings: (*a*) by surrounding the turns with insulating material such as paraffined paper, resin, etc.; (*b*) by separating the turns and adjacent connections beyond the maximum sparking distance, that is by using air as the insulation; and (*c*) by a combination of the first two, this being the

usual method of manufacture. Further, it should be realised that in a certain space at our disposal we may have either all copper or all insulation, the problem being to use the maximum amount of wire with the minimum of insulation compatible with absolutely perfect insulation, the ratio of wire to insulation depending on the method of winding and the maker's skill in insulating it.

For this reason it is usual for coils to take the general form as previously described, but circumstances may arise in which it is desirable from considerations of weight, portability, etc., to reduce the size of the secondary to the extreme limit. In such a case the length of the secondary must be reduced below the maximum spark length and therefore special arrangements must be made. One such method is to cast up the secondary solid, using paraffin, resin or other suitable insulation, the ends of the secondary being led out through ebonite tubes to discharger rods arranged at the right sparking distance. A second method is to immerse the coil bodily in an oil dielectric. This is a very efficient method, as it absolutely prevents brushing and other leakages. The coil, however, has to be wound dry, that is, no resin, paraffin, or beeswax need be used to insulate it, and when completed the coil should be exhausted in vacuo before the oil is allowed to run in. Coils of this kind, though very efficient, are usually messy and difficult to transport, and therefore are rarely met with.

A method of surmounting the difficulty is described by Wilson, wherein he uses two or more solid ebonite mouldings of the shape shown in Fig. 119 in diagram. Here A is one moulding, consisting of the end cheek and half the primary tube, this tube being feathered to fit into a similarly feathered tube moulded integrally with the cheek B, the two feathered parts constituting the

primary tube. The cheek B, moreover, has moulded to its outer diameter the secondary tube which fits within a recess C thrown up on the outer diameter of A. D, D represent the leading off tubes for the ends of secondary wire. With this construction it will be seen that, provided the winding itself does not break down, the chance of leakage to the primary is reduced to a minimum. Wilson also describes in this specification

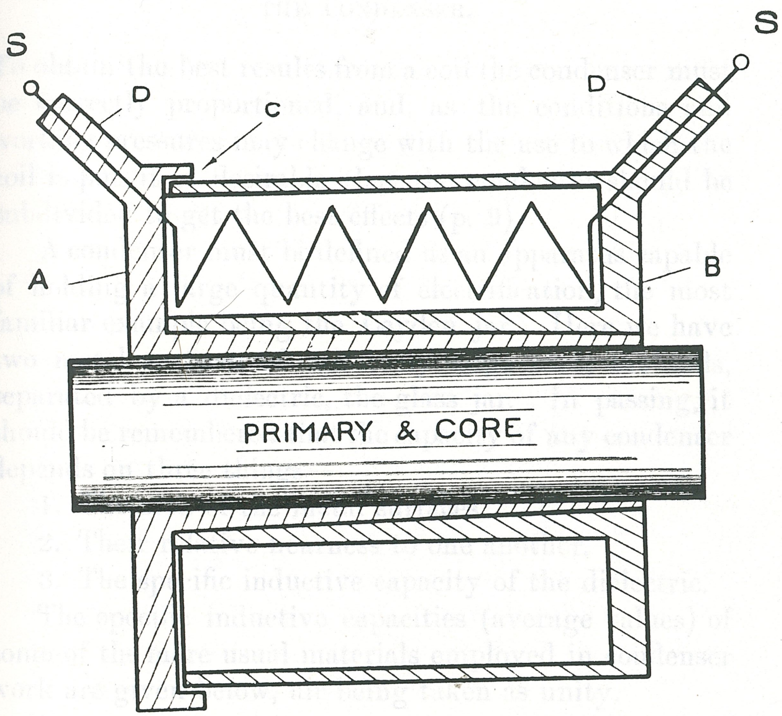


FIG. 119.—Wilson's arrangement for insulating secondary.

(No. 13509/1909) a method of winding a sectional secondary somewhat similar to Miller's (p. 98). To avoid special machinery and to obtain a better space factor he makes use of insulated strip conductor, wound in narrow sections in the usual way but one wire deep similar in appearance to a ring of tape. It is doubtful, however, whether there is any real gain in this method

of winding, especially as flat wire of this kind is extremely expensive.

Attention has already been drawn to the fact that the secondary has a fundamental capacity of its own, not only in relation to the primary, with the insulating tube acting as dielectric, but also with respect to the mutual capacity of the turns to one another. In a layer-wound coil it is obvious that each pair of layers forms a small condenser, the paper between each layer acting as a dielectric, the sum of the capacity of each layer multiplied by the total number of layers giving the total capacity of that section.

In a section-wound coil the capacity will be influenced by the propinquity of the conductors separated by the paper rings of dielectric as well as by the relative positions of the turns of wire themselves, and for this reason it would seem that a section-wound coil would have a greater secondary capacity than an equal size layer-wound coil. The capacity, it should be remembered, increases cumulatively, from the zero point in the centre of the secondary to the points of maximum potential at the terminals, and is next to impossible to determine in practice. It has, however, a very marked effect, especially in coils of poor output, the capacity effect of the secondary being responsible for the blue vivid sparks obtained at full spark length when the core is insufficient to allow enough energy to back up the gap and form an arc.

CHAPTER VII.

THE CONDENSER.

To obtain the best results from a coil the condenser must be correctly proportioned, and, as the conditions and working pressures may change with the use to which the coil is put, it is desirable that the condenser should be subdivided to get the best effects (p. 9).

A condenser must be defined as an apparatus capable of holding a large quantity of electrification, the most familiar example being the Leyden jar. Here we have two metal surfaces of relatively large area, the foils, separated by a dielectric, the glass jar. In passing, it should be remembered that the capacity of any condenser depends on three things—

1. The area of the metal surfaces.
2. Their relative nearness to one another.
3. The specific inductive capacity of the dielectric.

The specific inductive capacities (average values) of some of the more usual materials employed in condenser work are given below, air being taken as unity.

Air	1·0
Paraffin wax	1·996 to 2·32
Paper waxed	3·7
Paper dry	2 to 2·8
Resin	2·55
Shellac	2·75
Ebonite	2·29
Glass	3·01 to 9·9
Mica	8·0
Oil	2·05

If A = the area in square inches of one set of plates and K = the specific inductive capacity, and T = the thickness of the dielectric measured in inches, then the capacity C in microfarads $= \frac{AK}{T} \times \frac{2{\cdot}244}{10^7}$. Leyden jars do not commonly enter into the construction of induction coils, but they are frequently used in wireless work, in which case they are generally alluded to as "jars," a 2-pint jar having a capacity of ·001 and being about 4″ in diameter, and 5″ in height over the tinfoil.

In practice condensers are usually made flat, in book form, the dielectric being paraffined or resined paper, mica or micanite, varnished paper or silk. Ebonite and glass are sometimes used, but more particularly for high tension condensers, oil immersed, in wireless and for Tesla apparatus.

It is, therefore, comparatively easy to calculate the size of the condenser it is desired to build beforehand, final adjustment being made by adding or subtracting a few sheets when casing up.

In designing the condenser the desirability of approaching the foils or armatures should not lead one to overlook the necessity of interposing a sufficiency of insulating material, as besides the heavy stresses the insulating medium is called upon to bear (we have seen this may exceed 2,000 volts), it is also subject to dielectric hysteresis, that is, the insulator being mechanically stressed in opposite directions by electrical means in time tends to heat up, with consequent destruction of the condenser.

Most condensers for this reason give off sounds more or less loud when charged and discharged, and condensers for serious work running over long periods must be much larger than would otherwise be used, so as to dissipate the heat generated.

Mica or micanite are on this account sometimes used,

but these materials being extremely costly, it is preferable to use two or more condensers of relatively larger capacity in series, as they present a larger cooling surface to the air when so arranged. Moreover, with two equal condensers in series the voltage applied to the dielectric is halved (see p. 144), thereby still further decreasing the likelihood of breakdown, and should one burn out, the others will still probably carry on till repairs can be effected at leisure. This heating of the condenser is more readily understood when we reflect that its charge is stored on the surface of the dielectric and not on the armatures. Condensers are sometimes constructed of strips of paper treated on one side with metallic powder, similar to that used for packing tea, the strips being paraffined and rolled up, after which the rolls are squeezed flat and clips fitted to make contact to the metallic paint. Condensers of this type should be avoided, even for the smallest coils, as the area of contact between the collecting strips and the metal paint is insufficient to support the heavy condenser currents which have to be transmitted, and in time the surface of the paint round the connecting lugs will be found to have rotted away, rendering the condenser worthless. The usual materials employed for the foils are tin, lead and copper. For coil condensers of any ordinary size, tin-foil is usually used, the thickness being about ·5 mil; lead-foil can also be used, but presents no advantage. Copper-foil is frequently specified in the construction of oil-immersed condensers for high tension work, where tin-foil would be too delicate. Its use is also essential in certain air-cooled condensers constructed of mica which sometimes attain a temperature which would melt ordinary tin-foil. In very large condensers sheet zinc is often used.

The usual method of constructing a condenser is as follows. A board is taken, into which long steel pins

are driven at intervals to form a cage for the condenser sheets as they are built up (Fig. 120). The number of sheets of foil and paper having been determined, one-half of each are arranged to right and left, respectively, of the board. That is, if 100 foils and papers are to be made up, 50 foils are arranged on the left with 50 papers, and 50 foils are also placed on the right with an equal number of sheets of paper. This arrangement avoids confusion, which is likely to arise in the course of construction. The paper used must be of the best quality, quite free from pinholes, dirt, or other blemishes.

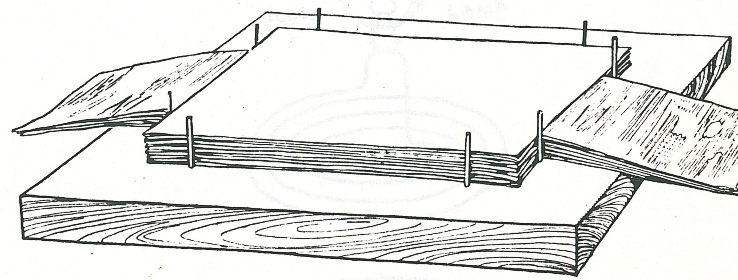


FIG. 120.—Condenser building jig.

This can best be ascertained by holding the paper, sheet by sheet, against a strong light and examining carefully every portion. The thickness of paper for paraffined condensers varies usually from 2 to 10 mils, according to the size of the coil; but it is desirable to use two papers of half the thickness, when possible, so as to minimise the likelihood of weak spots in the paper. One paper is now laid on the board between the steel pins, then one foil to the right, then one paper and another foil, this time to the left, and so on and alternately till the whole 100 foils and papers are used up. The foils are usually cut rather longer than is required so that they project at the ends to right and left alternately to form connections. If it be desired for any reason to bring both connections to

the one end of the condenser, one of the corners may be cut off and the foils laid on as before; but one foil is laid on one side and the second foil on the other, and so on as usual (Fig. 121). Generally speaking, the first described arrangement is the better as the foils at the end present a larger contact area. The condenser being now completed, stiff cardboards are placed either side and the whole condenser is tightly wound with tape, after which it should be placed in a light wooden box to prevent mechanical injury. The lugs of the foils should be folded tightly together on either side and soldered to flexible copper leads. Ordinary solder can

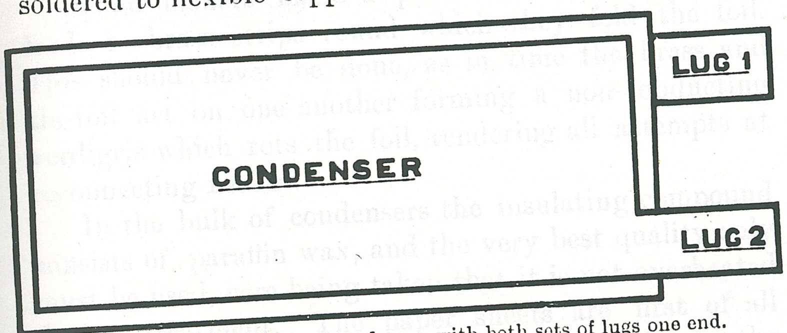


FIG. 121.—Arrangement of condenser with both sets of lugs one end.

be used, but as its melting-point is much higher than that of the foil it will be found that even with the greatest care, holes are liable to be burnt in the foil, and, therefore, a lower melting-point solder can be more advantageously used. This can be composed of lead, 8 parts; tin, 4 parts; bismuth, 15 parts, and cadmium, 3 parts. Unless a very low melting-point is desired, the cadmium can be omitted. Care should be taken to keep the length of the connections from the condenser to the interrupter as short as possible, and of ample size. The leads should preferably be of parallel stranded flexible wire, large in section, not twisted, in view of the extremely high-frequency current they have to carry, and for this reason it is preferable

to construct the coil and condenser separately, so that the latter can be placed directly adjacent to the interrupter, where it is not an integral part of the whole apparatus, and not, as is usual, in the base of the coil. The writer has seen coils and condensers working yards away from the interrupter, festoons of wire connecting the two. Obviously efficiency cannot be thus attained, and switch-tables are very often great offenders in this respect. A simple experiment will demonstrate the

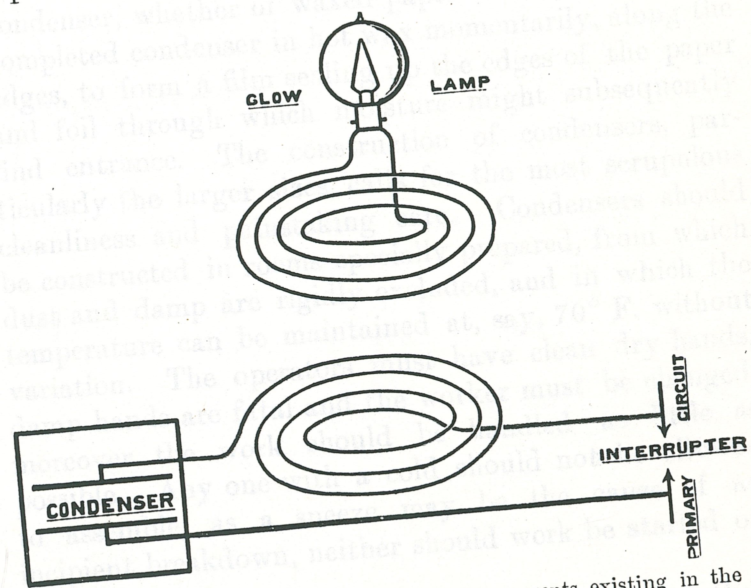


FIG. 122.—Experiment demonstrating H.F. currents existing in the condenser circuit.

extreme rapidity of the oscillations in the condenser circuit. Let a flat spiral be introduced between the condenser and the interrupter, and a second spiral be approached with a low voltage lamp connected, as in Fig. 122. The coil should now be switched on with a medium gap, when the lamp will light up brightly, varying in intensity as the coil is approached or receded from the fixed coil in the condenser circuit, thereby

coupling the two tightly or loosely. It will be noticed that when tightly coupled the output of the secondary discharge falls off very considerably, or may even cease, and that when the movable lamp circuit is entirely removed the coil does not work so well, owing to the self-induction introduced by the few turns of wire in the spiral. If, however, this spiral be straightened while the coil is working it will immediately resume its normal functioning. Hence, the desirability of heavy, non-inductive, short leads in the oscillating circuit is amply demonstrated.

Some makers make a practice of soldering their leads to brass strips round which they fold the foil. This should never be done, as in time the brass and tin-foil act on one another forming a non-conducting verdigris which rots the foil, rendering all attempts at reconnecting useless.

In the bulk of condensers the insulating compound consists of paraffin wax, and the very best quality only must be used, care being taken that it is not overheated during treatment. The paper sheets are first of all carefully dried in an oven, and then plunged into the trough of melted paraffin, after which when cold they are built up in the manner already described.

After the condenser is completed it is placed in a tray and heated gently so that the surplus wax may drain away, and then pressed in a standing press till cold. It is then put in its wooden box and fixed there by a little molten wax to exclude air and damp which might find its way in through any loose sheets of the dielectric.

Where impregnating tanks are available the condenser may be made of dried paper and then impregnated after with wax, being subsequently pressed. One of the best methods of manufacturing condensers is to have the condenser papers or mica sheets arranged

on a hot plate adjacent to the wax tank. This latter is fairly large to allow manipulation and provided with a shelf just below the surface of the wax, the condenser being built up in the hot wax itself upon the shelf, the paper being taken directly from the hot plate. When the completed condenser is removed from the tank for pressing, the paper is already permeated with wax and the possibility of dampness entering in almost entirely precluded. Nevertheless it is a wise precaution in any condenser, whether of waxed paper or mica, to dip the completed condenser in hot wax momentarily, along the edges, to form a film sealing up the edges of the paper and foil through which moisture might subsequently find entrance. The construction of condensers, particularly the larger sizes, calls for the most scrupulous cleanliness and painstaking care. Condensers should be constructed in rooms specially prepared, from which dust and damp are rigidly excluded, and in which the temperature can be maintained at, say, 70° F. without variation. The operators must have clean dry hands, damp hands are fatal and the worker must be changed, moreover the work should be handled as little as possible. Any one with a cold should not be allowed to assemble, as a sneeze may be the cause of an incipient breakdown, neither should work be started on a damp day.

These instructions may appear fantastic, but they are really essential to the production of a first-class condenser, which is really one of the most difficult pieces of electrical apparatus to construct, and apply in a lesser degree to condensers made of varnished cloth, mica, and the like. The finished condenser must be carefully tested for capacity, resistance, and breakdown. The first will naturally vary with the size of the coil and its uses, but will rarely exceed 5 microfarads, being more usually a quarter that value for

large coils and about 0·5 mfd. for small ones. The resistance should be about 2·5 megohms for every mfd., but this is not so essential as the breakdown test, as a certain amount of leakage in parallel with the condenser is by no means detrimental to its action as long as it does not imply dielectric weakness. This last must be tested by applying A.C. for periods varying with the duty the condenser is likely to be called on to perform. For coils of 10″ and over, if working on 100-volt circuits, the A.C. test should be 500 volts applied for 5 minutes at 50 cycles, and if for 200-volt circuits 1,000 volts for the same time. At the end of the test the condenser should be flashed several times at double these pressures respectively. The temperature of the condenser at the conclusion of these tests should not have risen unduly, and the wax or other dielectric should show no tendency to exude from the containing box. The resistance of the condenser should be again checked to ascertain that it has not fallen during the testing, but the condenser must be allowed to cool first. When carrying out tests for resistance and capacity, it should be remembered that the dielectric of the condenser takes some little time to absorb its full charge, and therefore the application of the test should be continued till the measurements show a constant value.

The test for resistance is best taken with a megger, though a Wheatstone Bridge can also be used; the voltage generated by the megger more nearly approximates to working conditions, however, as the resistance of the material varies considerably with the voltage applied.

The capacity may be measured accurately enough in condensers larger than 0·1 mfd. by the method of direct substitution.

In the larger size coils the condenser is usually

subdivided so as to proportion it to the current used. This is sometimes accomplished by the use of a progressive switch making contact with more or less of the sections of the condenser, which for this purpose should be of equal value, thereby rendering a considerable number of divisions necessary and increasing the expense.

A better plan is to use links or plugs, whereby sections of various values can be added, thereby paralleling up the desired capacities which can be selected at will. For a given number of subdivisions values in even numbers give a greater number of combinations than a decimal arrangement, thus with four condensers of the values 1, 2, 4, 8, give 15 possible arrangements, whereas 1, 2, 2, 5, give only 1 to 10. For all ordinary purposes the use of two condensers giving four values is sufficient, thus 1 mfd. and ·5 mfd. can each be used separately or in parallel giving 1·5 mfd. in all; further, the two sections can be used in series giving a fourth capacity of ·33 mfd.

The value of a number of condensers in parallel is the sum of their separate capacities; thus, if A be the capacity of the first and B the capacity of the second, etc., the total capacity $K = A + B$, etc.

If the condensers are in series

$$K = \frac{A \times B}{A + B}, \text{ etc.}$$

that is, the total capacity is less than that of the larger of the two.

For example, taking the capacities above mentioned I mfd. and ·5 mfd.

$$K = \frac{1 \times 0{\cdot}5}{1 + 0{\cdot}5} = \frac{0{\cdot}5}{1{\cdot}5} = \frac{1}{3} \text{ or } 0{\cdot}33 \text{ mfd.}$$

If we have three or more condensers in series of

values A, B and C, the total capacity is given by the formula

$$K = \frac{A \times B \times C}{BC + AC + AB}$$

It will be noticed that when two condensers of equal values are in series the voltage over each condenser is halved, and when the capacities are unequal it is in inverse proportion to their capacities.

CHAPTER VIII.

INTERRUPTERS.

Before reviewing the various types now used it may be well to consider the chief points required in a good interrupter, as ascertained from the theory of coil circuits in the preceding pages. Briefly they are as follows: (1) the speed of interruption should be variable, so that the interruptions can be made to synchronise with the time constant of the coil, in other words, the frequency of the break can be varied to suit the coil (p. 4); and (2) the relation of period of make to period of break, or the time economy (p. 13), must also be variable, so that the interrupter may accommodate itself to the self-induction of the coil and the voltage of supply.

Mechanically, interrupters should be of solid construction, owing to the high value of the currents broken and the destructive nature of the inductive flash.

It is desirable that the contacts should separate with a high lineal or peripheral speed even when oil or gas quenched, and on this account breaks of generous proportions should be chosen.

Interrupters may be roughly divided into four classes:—1. Platinum interrupters. 2. Mercury contact interrupters. 3. Mercury jet interrupters. 4. Electrolytic interrupters.

From a practical point of view platinum interrupters are only suitable for low inputs, 300 watts being about the reasonable limit, above this, mercury or electrolytic interrupters must be used.

Of the mercury interrupters the mechanical plunger make and break of Foucault is rarely now used, the turbine type of break having almost entirely superseded it.

The turbine break may be divided into two classes, the gas quenched and the oil quenched.

The gas quenched is exceedingly clean and reliable, running for days together without attention if generously designed, and giving sharp interruptions varying in periodicity between wide limits. It has, however, the disadvantage that gas must be used in the mercury chamber, or failing this acetone or ether.

The oil-quenched break has all the advantages above described and gives even heavier discharges, in addition to being self-contained and portable, but has the disadvantage of gradually losing its oil owing to capillary attraction and to splashing of the contacts which render it messy to handle, in addition to which cleaning is a particularly unpleasant operation.

Electrolytic interrupters give very heavy discharges in the secondary, and are therefore used to obtain X-ray photographs where short exposures are necessary. Their use, however, considerably shortens the spark length unless special arrangements are made. They are, however, clean and require little attention if provision for cooling the electrolyte is arranged.

From a medical point of view they make rather an alarming noise and should be made to work out of doors, so as to get rid of the noise and the acid vapours given off during action.

Hammer Breaks.

The commonest form of platinum interrupter, due to Apps (Fig. 123), and still used on coils, consists of a steel or brass spring A, carrying at one end an iron hammer B, which is attracted by the core, the other end being supported by a bracket C. A contact stud of platinum D is located at any point from half-way up to the top as illustrated, and makes contact with a

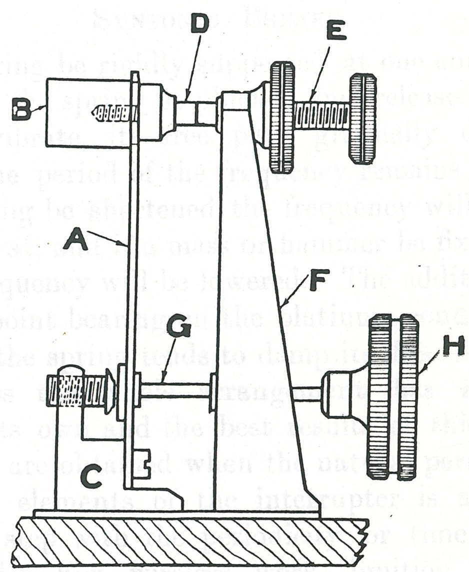


Fig. 123.—Apps platinum hammer break.

platinum-tipped screw E, supported by the pillar F. As soon as the magnetism of the core is sufficiently strong it will attract the hammer B and contact will be broken between D and E, whereon the spring again flies back into place and the cycle of operations is repeated. The disadvantage of the arrangement, as it now stands, is that if the spring A is rather weak the hammer will be attracted before the magnetism has grown to its full extent. To overcome this a screwed tensioning rod G

is arranged to press A backwards more or less as the knurled head H is turned to right or left. The effect is to strengthen or weaken the spring A, thereby varying the value of the current in the primary necessary to magnetise the core sufficiently to attract the hammer.

Despite the addition of the tensioning screw large currents are difficult to handle with this break owing to the low velocity with which the platinum contacts break (see Oscillograph, Fig. 27), thereby enabling the

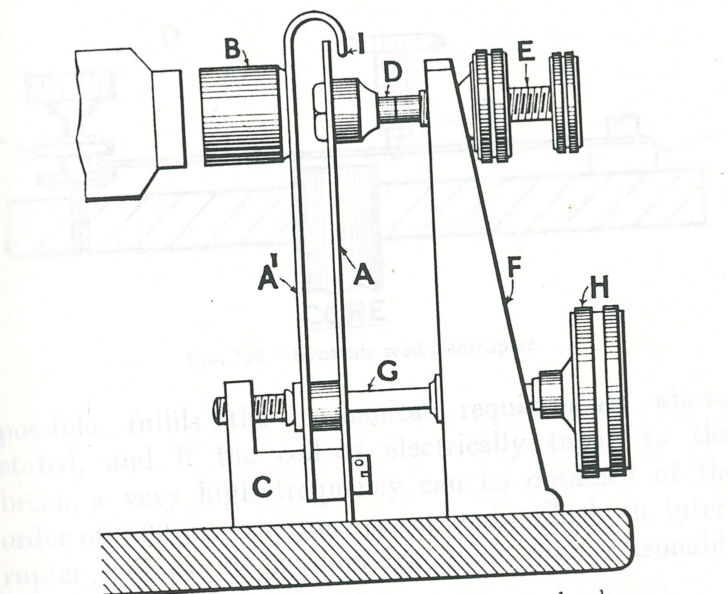


Fig. 124.—Double spring platinum hammer break.

platinum studs to weld together or stick. To get over this difficulty a modified form of interrupter using two springs, Fig. 124, is more generally used for platinum interrupters. Here the hammer B is mounted alone on a single stiff spring A', the head of the hammer having an extension which engages with the true platinum spring A after it has moved a certain distance. The effect of this is to allow the hammer head to acquire

a certain velocity before the platinum spring A is engaged, so that the platinum points are immediately separated at full speed instead of having to gain its own velocity as in the case of the plain interrupter. In this arrangement a tensioning device is also added to vary the current strength necessary to break contact, and a screw is also frequently arranged at I, to limit the travel of the head before the platinum spring is struck off contact.

Syntonic Breaks.

If a spring be rigidly supported at one end and the free end of the spring be plucked and released the free end will vibrate, its free path gradually decreasing although the period of the frequency remains the same. If the spring be shortened the frequency will increase, and *vice versâ*, and if a mass or hammer be fixed at the end the frequency will be lowered. The addition of the platinum point bearing on the platinum contact or the middle of the spring tends to damp its free movement, nevertheless the whole arrangement has a natural period of its own and the best results of this class of interrupter are obtained when the natural period of the mechanical elements of the interrupter is as near as possible in step with the periodicity, or time constant, of the coil. For wireless work, ignition coils for internal combustion engines and other purposes, it is sometimes necessary to use a very much higher rate of vibration than the comparatively slow breaks above described, and it is then necessary to use a multiple of the time constant, tuning the vibrator as nearly as possible to twice, four, or six times the natural period of the coil. The effect of this is greatly to shorten the available spark length, but the total energy output is not materially decreased since the frequency is increased proportionally.

A reed break of this description is shown in Fig. 125. Here A represents the steel spring or reed firmly clamped to a standard B and free to vibrate at its extremity between two rubber buffers C which damp the vibration of A and limit the mean free path of its excursions, these buffers being capable of adjustment to and from the core by means of the milled headed screw D. About the centre of the spring are placed the platinum studs E. This arrangement, by careful selection of the gauge of the spring A, as nearly as

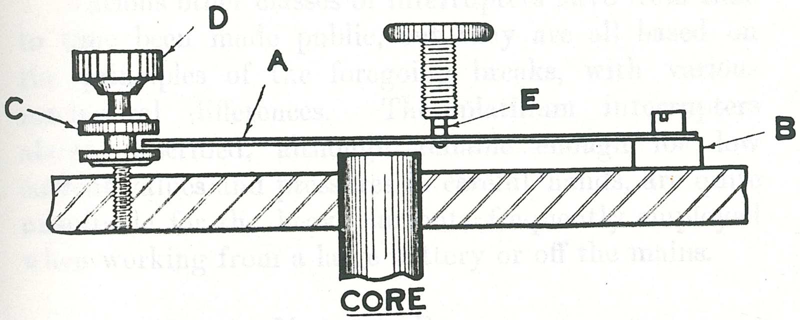


FIG. 125.—Syntonic reed interrupter.

possible fulfils the mechanical requirements above stated, and if the coil is electrically tuned to the break, a very high frequency can be obtained of the order of 500 interruptions per second. Such an interrupter will run a considerable time with reasonable attention.

ATONIC BREAKS.

The breaks above described are syntonic, that is they depend to a great extent on the period of vibration of the spring employed; there is, however, a second class of platinum interrupter which is atonic, that is it has no natural period of vibration and depends on the period of the coil to impress the frequency of interruption on

it. To this class belong the interrupters of Carpentier and others.

Carpentier's break is shown in Fig. 126, and consists of a soft iron armature A pivoted loosely at one extremity against the supporting block B. A light spring C tends to keep the armature away from the iron core and pressed against the set screw D (generally tipped with ivory). The free end of the armature A, in the course of its movement, can engage with a light contact spring E, carrying one of the platinum contacts F, which it strikes off contact; the magnetic attraction

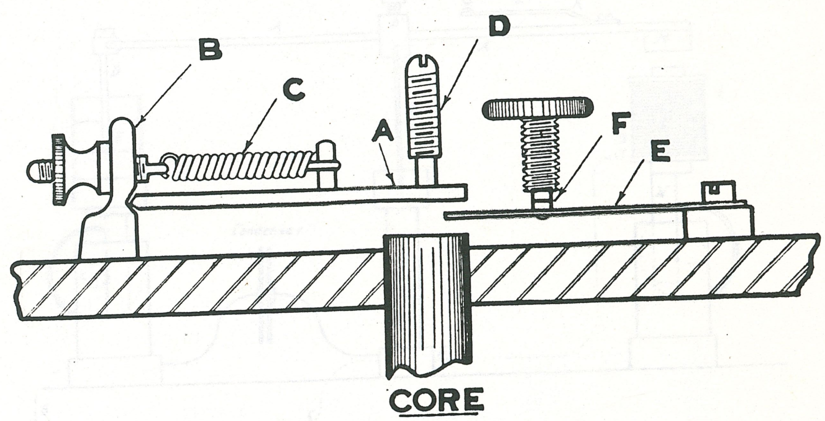


FIG. 126.—Atonic interrupter of Carpentier.

being thereby destroyed, the spring C, aided to some extent by the cushioning effect of E, returns A to its normal position. It will be noticed that there is some little clearance between the tips of the armature A and the contact spring E which is adjustable by means of the screw D. This clearance enables the time of magnetisation to be varied between wide limits, as it is obvious the larger the distance existing between A and E the greater will the current value be at the time of rupture and, incidentally, the higher will be the velocity of the blow of the armature on striking off contact.

It will be noticed that this break does not differ widely from that illustrated in Fig. 124, the main difference being in the fact that while Fig. 126 is truly atonic, Fig. 124 depends to a great extent on the natural resiliency of both its platinum spring and also the hammer spring.

It is claimed that the Carpentier type of break being atonic will work on alternating current circuits, but the writer has not verified this, as its application seems doubtful.

Various other classes of interrupters have from time to time been made public, but they are all based on the principles of the foregoing breaks, with various mechanical differences. The platinum interrupters above described, although reliable enough for low current values and pressures in careful hands, are quite unsuitable for the heavy currents frequently employed when working from a large battery or off the mains.

Mercury Breaks.

The first improvement attempted was to substitute a metal rod, generally copper, dipping into a pool of mercury for the two platinum studs hitherto used.

A break of this type is illustrated in Fig. 127. Here AA is a rigid beam longitudinally adjustable through the support D and set screw C, the whole being pivoted by the spring O, which is held by the upright bracket J. One end of the beam carries the hammer H which is attracted by the magnet I, which is adjustable by the rack and pinion N, the break circuit of this magnet being interrupted by the platinum spring KL, and studded screw M. On the circuit being closed H will be attracted by the magnet I, contact will be broken, and the beam released in the usual way. The other end of the beam, however, carries an amalgamated copper rod E dipping into a pot G containing mercury F.

This pot is adjustable for height by a rack and pinion in a similar way to the magnet I. Therefore, as the beam rocks to and fro contact is made and broken between the rod and the mercury in the pot (circuit 520E6). The period of contact is variable by adjusting the distance the rod dips into the mercury pool, but the period is dependent on the adjustment of the local circuit (1234) by the contacts at L.M. To extinguish

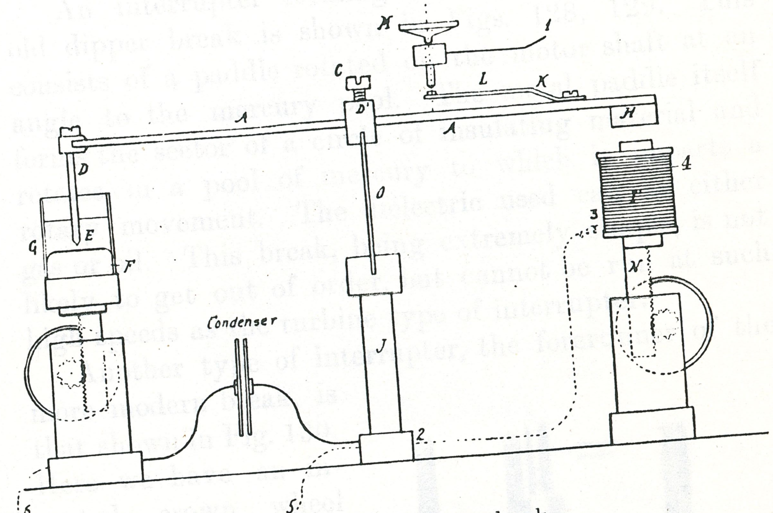


Fig. 127.—Mercury dipper break.

the flash at break the surface of the mercury is covered with paraffin or methylated spirits. Fairly large currents can be handled by breaks of this description, but if high values are interrupted the explosions which result at the point of rupture throw out the liquid covering the surface of the mercury. The entry of the rod frequently causes surface disturbances or periodic swaying of the mercury. To obviate this an iron washer is sometimes floated on the surface of the mercury to damp out the ripples. Various modifications of this break have been from time to time suggested, such as the use of two mercury pots as in the

original Foucault interrupter, the current being conveyed from one mercury pool through a copper dipper,

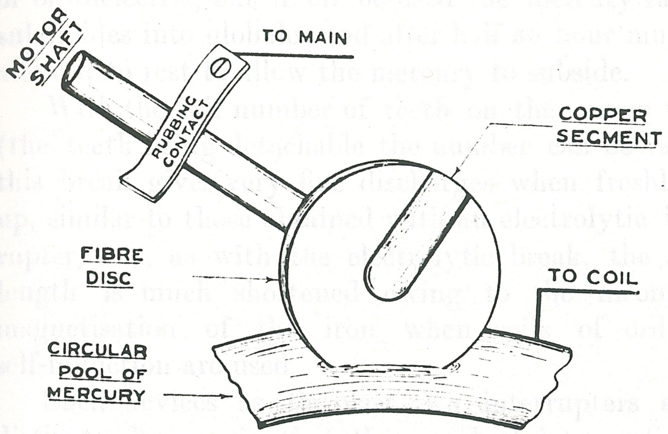


FIG. 128.—Mackenzie Davidson break (diagram).

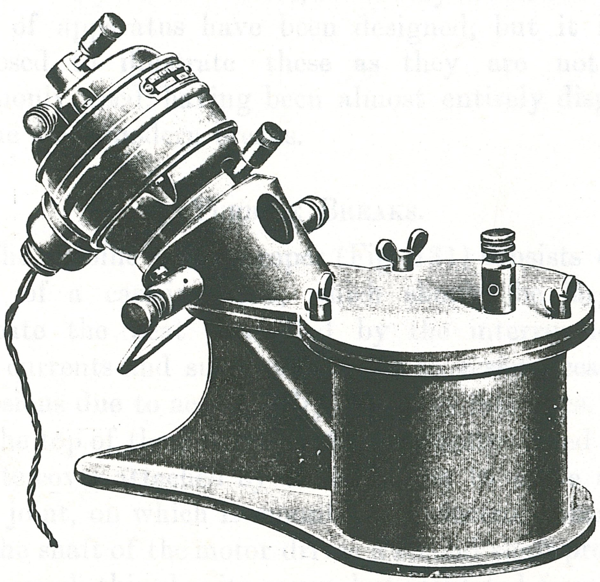


FIG. 129.—Mackenzie Davidson break, general appearance.

which does not leave the mercury, back to the second dipper, which serves as the true interrupter.

Sometimes the mercury break is arranged to be

operated by the magnetism of the core itself. Apps' break has been so modified, the platinum on the blade being replaced by a curved rod dipping into the mercury pot, but all such breaks are slow in action and the next step was to work the dipper rod vertically in and out of the mercury by means of an electro-motor, the rod being operated through the medium of a crank, eccentric, or slot and pin mechanism.

An interrupter forming an improvement on the old dipper break is shown in Figs. 128, 129. This consists of a paddle rotated on the motor shaft at an angle to the mercury pool. The metal paddle itself forms the sector of a circle of insulating material and rotates in a pool of mercury to which it imparts a rotary movement. The dielectric used can be either gas or oil. This break, being extremely simple, is not likely to get out of order, but cannot be run at such high speeds as the turbine type of interrupter.

Another type of interrupter, the forerunner of the more modern break, is that shown in Fig. 130. Here we have an inverted crown wheel driven by a belt from a small motor. The bottom of the shaft drives a small toothed wheel pump submerged in mercury. The outlet from the pump terminates in a movable nozzle from which the issuing jet of mercury impinges on the rotating teeth of the crown wheel. The jet being movable in a vertical direction can play on the teeth

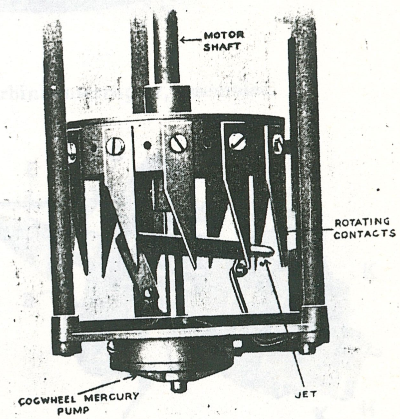


FIG. 130.—Max Levy interrupter.

anywhere from the tips to the root, thereby varying the period of contact. The interrupter runs either in a gas or oil dielectric, but if oil be used the mercury rapidly subdivides into globules and after half an hour must be allowed to rest to allow the mercury to subside.

With the full number of teeth on the crown wheel (the teeth being detachable the number can be varied) this break gives very fine discharges when freshly set up, similar to those obtained with an electrolytic interrupter, but, as with the electrolytic break, the spark length is much shortened owing to the incomplete magnetisation of the iron when coils of ordinary self-induction are used.

Such devices as the last two interrupters are a distinct advance, in that the speed of interruption is more directly under control, and many variations in the form of apparatus have been designed, but it is not proposed to illustrate these as they are not now commonly used, having been almost entirely displaced by the more modern breaks.

Turbine Breaks.

The turbine break proper (Fig. 131) consists essentially of a cast-iron pot, which should be large to dissipate the heat generated by the interruption of large currents and sufficiently stout to resist occasional explosions due to accidentally weak gas mixtures.

The top of the pot (Fig. 132) is usually closed by an ebonite cover attached by thumbscrews to make a gas-tight joint, on which is mounted the electro-motor.

The shaft of the motor drives a second shaft protruding through this ebonite cover, but insulated from it by an ebonite or fibre sleeve to prevent any chance extra current breaking down the motor windings. The shaft in the pot carries a cone, usually of iron or wood, drilled with two passages terminating in two iron nozzles

which are arranged to protrude from the top of the cone at opposite ends of a diameter. The bottom of the cone

Fig. 131.—Mercury turbine interrupter, assembled.

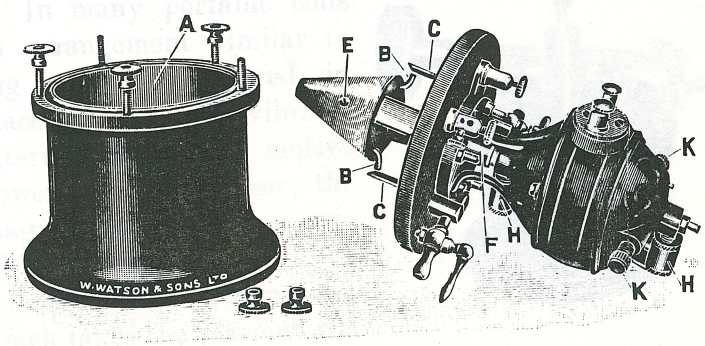


Fig. 132.—Mercury turbine interrupter, taken apart to show mercury jet coils and contacts.
A. Mercury pot. B. Jets. C. Contact segments. E. Jet cone. F. Coupling sleeve between cone and motor. H. Lubricators. K. Motor brushes.

is immersed in a pool of mercury which rises in the passages in the cone by centrifugal force and sprays out from the nozzles in jet form. Arranged concentrically with the jets and about $\frac{1}{16}''$ distant are the contact segments, usually of copper, against which the jet of mercury impinges. The circuit is thus from one segment through the column of mercury, the mercury pool, and the second column of mercury to the second segment. Each revolution of the motor thus gives two interruptions.

Should the motor for any reason fail, the mercury falls in the jet passages and the circuit is automatically broken; there is thus no danger of burning out the coil or blowing the fuse, and accidentally switching on the main current without first starting the motor will produce no ill effect. In order to vary the duration or length of contact in these interrupters the usual method is to make one of the two contact segments triangular in shape, this segment being movable in a direction normal to the plane of the jets. Thus, when fully depressed, the jet sweeps the whole contact area and, when nearly fully raised, only the apex of the triangle. In this way any desired duration of contact can be obtained. Some makers provide fixed contacts only, the interrupter being tuned to the particular coil for which it is supplied, but generally speaking this is not desirable, the additional refinement of adjustable contact length being necessary to obtain the best time economy under varying conditions. Occasionally four contacts are arranged in the circle, thereby giving four interruptions per revolution. Such an arrangement is usually found where the pressure of the mains is high and the self-induction of the coil abnormally low.

Another method of varying the length of "make" is shown in Fig. 133. Here we have the mercury jet device rotating as before, but the mercury impinges on a sector free to hinge about one extremity. By swinging

the blade more or less from its true centre the time of contact can be varied at will, as when the sector is truly concentric the jet sweeps the whole length of the blade, but when swung fully out only that part adjacent to the pivot. It is claimed, moreover, for this device that the circuit is closed gradually through the mercury

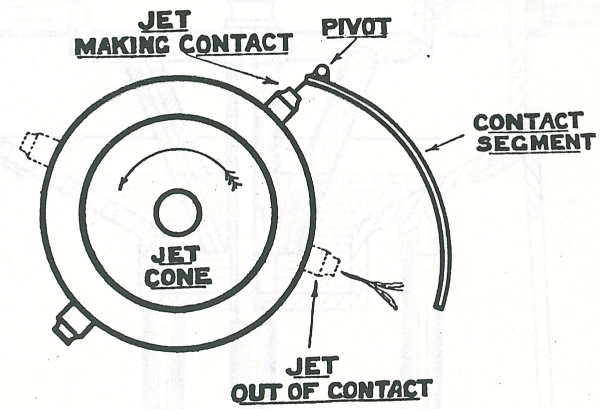


FIG. 133.—Variable contact segment.

column which decreases in resistance as the nozzle relatively approaches the sector, thereby diminishing the likelihood of inverse current being developed.

In many portable coils an arrangement similar to Fig. 134 is employed in place of the old vibrator interrupter, the motive power being, as before, the magnetism of the iron core which is used to attract a rotating iron armature, which takes the place of the usual electro-motor. The device is started by spinning with the fingers. The mercury rises in the jet passages

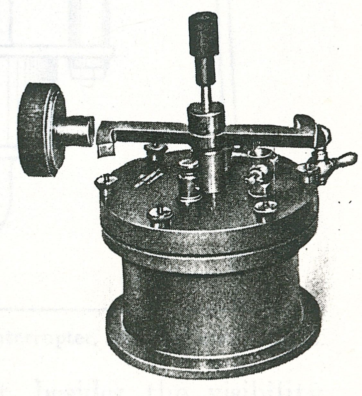


FIG. 134.—Mercury auto-interrupter.

and completes the circuit whereon the iron armature is attracted to the core. Precisely at the moment the armature is opposite the core the mercury jet is arranged to interrupt the circuit, and, the magnetism ceasing, the momentum of the armature causes the mercury cone to continue revolving until the circuit is again closed, and so on. Such an auto-interrupter is a great advance on the old platinum break, but it is not very flexible and its speed varies as the voltage increases. It is therefore necessary to vary the number of layers of primary or else to use a series resistance.

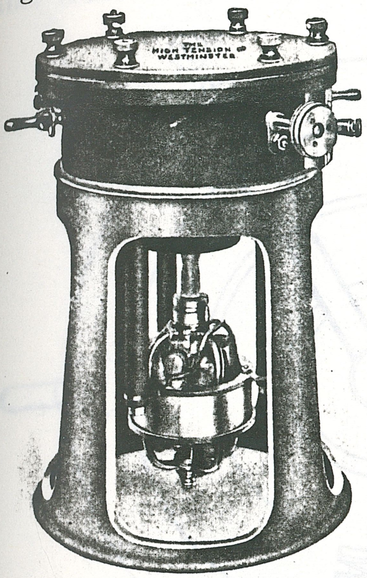


FIG. 135.—Motor under driven mercury interrupter.

Figs. 135 to 138 show an interrupter having several points of novelty.

In this design of interrupter the cone and jets are of cast iron, the cone being driven from a motor located below the mercury pot, instead of above, as is the usual practice, the bearing being a long sleeve screwed into the bottom of the pot. The base of the cone dipping into the mercury floats thereon, so that the weight of the jet cone is not taken by the bearing and an efficient gas seal is provided. The contacts are two copper segments, as usually arranged, but one is free to tip up in a vertical direction, being controlled by an ebonite hand wheel outside the mercury pot, hence the arc of contact can be varied

as desired. A triplex glass lid can be fitted instead of the usual cast-iron cover so that the action of the interrupter can be viewed from without. The chief

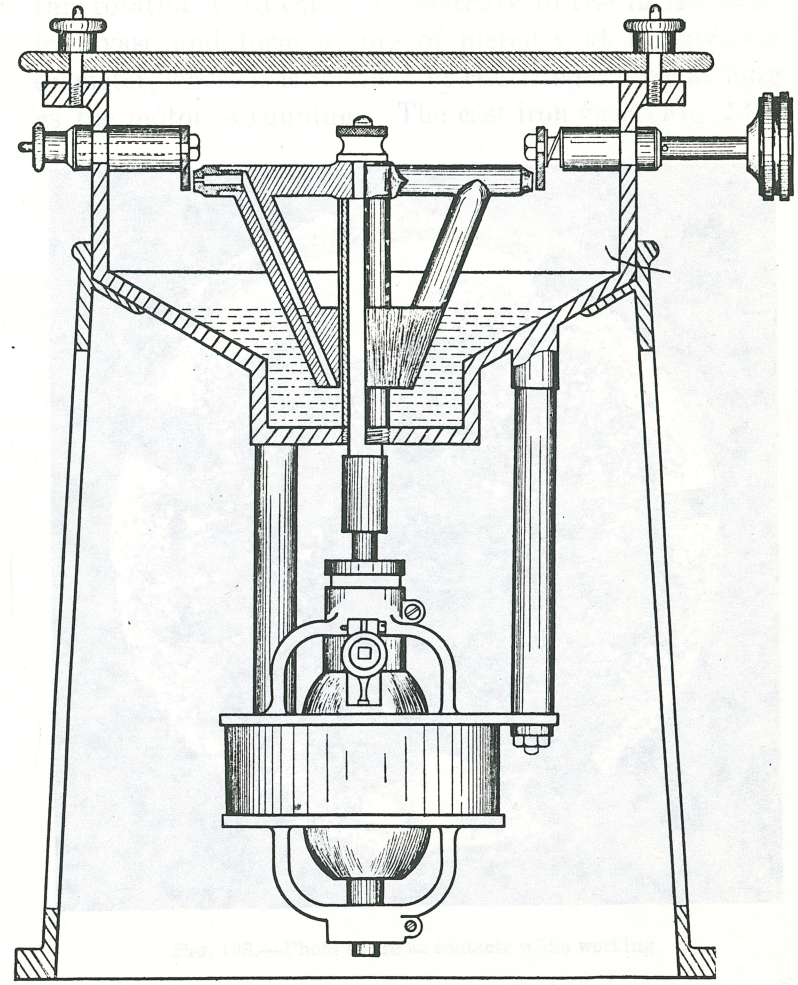
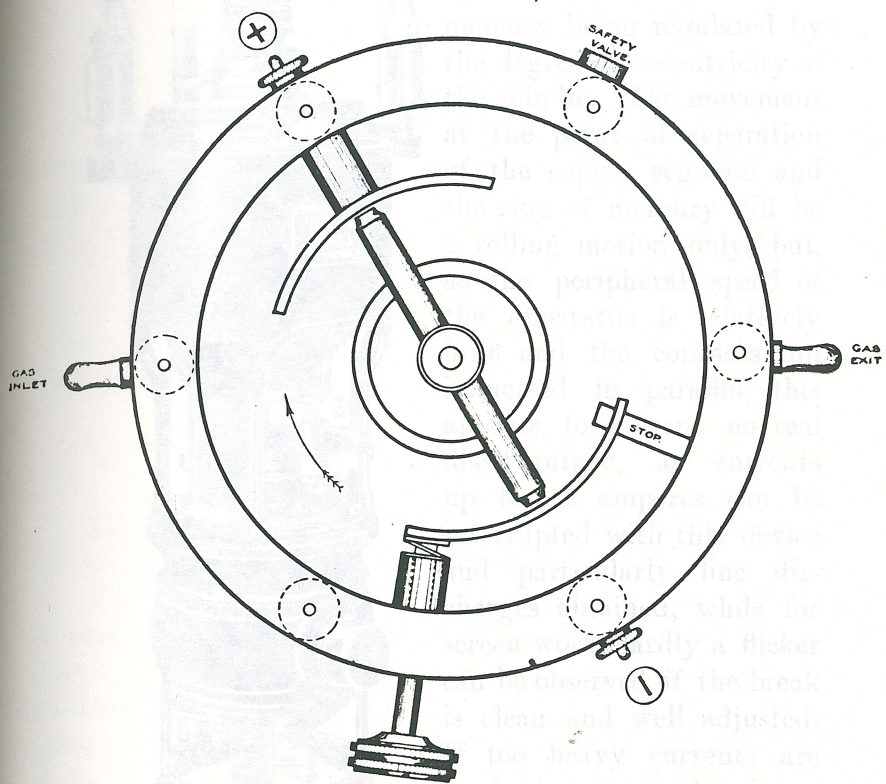


FIG. 136.—Motor under driven mercury interrupter, sectional arrangement.

advantage of this arrangement, besides the visibility, is the ease with which the jet device may be inspected, as the jet cone can be taken out by merely removing a milled nut and the contact segments can be cleaned

without lifting the motor or detaching the motor connections, as is usually the case.

The method of driving the jet cone from beneath was first suggested by Major C. E. S. Phillips in the *Proceedings of the Physical Society*, and independently designed by the writer with the addition of the movable contact segments. It was not until some time



Plan. Time economy of contacts ·5.

FIG. 137.—Motor under driven mercury interrupter.

afterwards that the similarity of the arrangements was discovered and brought to the writer's notice.

The latest form of this break is designed to run on the 440-volt mains and will handle up to 12 K.V.A.

A type of interrupter based on an entirely different

principle is the Tesla (Fig. 139). Here the vessel containing the mercury is vase-shaped, and is itself rotated by the motor which is situated below it. The effect of this rotation is to cause the mercury to rise in the cast-iron vase and form a ring of mercury at its greatest diameter, where it is retained by centrifugal force as long as the motor is running. The cast-iron vase (Fig. 140)

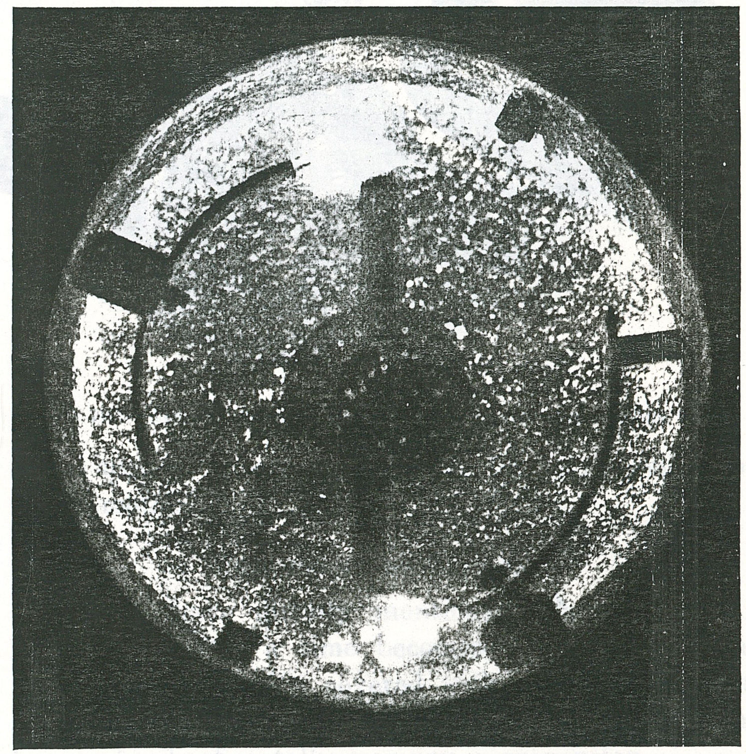


FIG. 138.—Photo of arc at contacts while working.

and the mercury form one pole of the apparatus, and to complete the circuit intermittently a fibre wheel, roughened with toothed indentations and carrying a copper segment (Fig. 140), is introduced about the centre of the vase, being allowed by suitable eccentric gear to dip more or less deeply into the rotating ring

of mercury. The diameter of the ring of mercury being very much larger than that of the fibre wheel the speed of the latter is considerable, the arrangement resembling somewhat an epicyclic gear. The result is that the copper segment, rotated as part of the fibre wheel, dips into and leaves the mercury with considerable velocity, the duration of its stay beneath the surface of the mercury being regulated by the degree of eccentricity of the spindle. The movement at the point of separation of the copper segment and the ring of mercury will be a rolling motion only, but, as the peripheral speed of the apparatus is relatively high and the contacts run immersed in paraffin, this appears to present no real disadvantage, as currents up to 15 amperes can be interrupted with this device and particularly fine discharges obtained, while for screen work hardly a flicker can be observed if the break is clean and well adjusted. If too heavy currents are used, however, the interrupter is liable to spue out the paraffin and make a very objectionable mess. Owing to the centrifugal action on the mercury it does not appear to split up into minute globules as do other oil-quenched (and to a certain extent gas-quenched) breaks, and no emulsion is formed

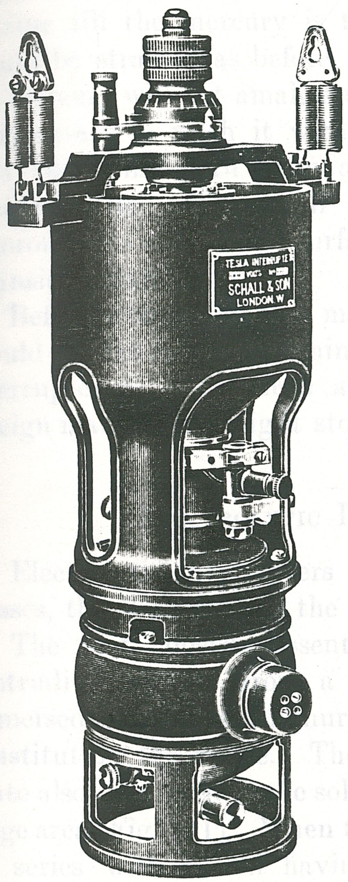


FIG. 139.—Tesla interrupter.

other than that due to the natural oxidation of the mercury. As is usual with turbine type breaks, when the device comes to rest the circuit is automatically broken. The apparatus is frequently suspended on spiral springs to reduce the noise due to the vibration of the motor.

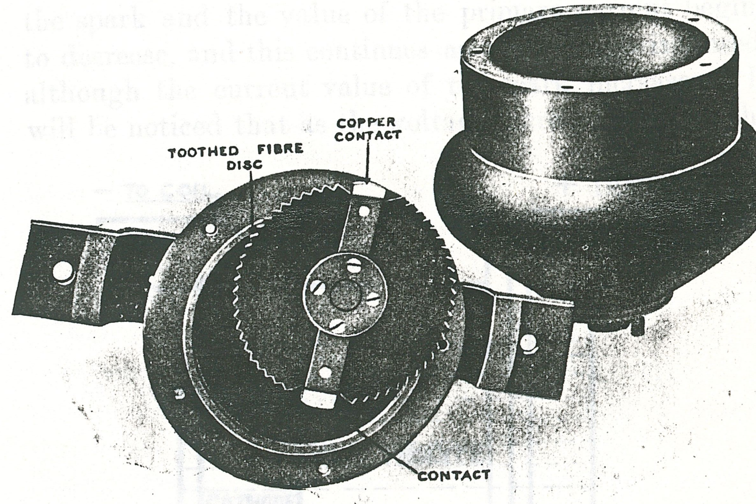


FIG. 140.—Tesla interrupter, showing mercury vase and rotating wheel.

Treatment of Mercury.

As we have already mentioned, the mercury in interrupters after a time becomes dirty, that in gas interrupters becoming covered with a grey-black dust, and in oil-quenched interrupters with a black slime containing beads of metallic mercury in suspension.

Mercury dirtied in a gas break should be washed in an earthen pot with clean water first, then with benzine or petrol, stirring the while to bring the surface of the mercury well into contact with the spirit. This washing must be repeated till the mercury is quite clean, when it should be filtered through two or three thicknesses of close linen or through chamois leather.

Mercury from an oil break is much more difficult to clean. First empty the mercury and the black sludge (which may contain a quantity of mercury in suspension) into an earthenware jar, and add paraffin, stirring the while. Empty the paraffin, and repeat, till the mercury settles to the bottom of the pot. Then use petrol or benzine till the mercury is thoroughly clean, when it should be strained as before. Despite careful washing the mercury will not amalgamate sometimes, and it may be necessary to wash it with a hot solution of caustic soda, then rinse with water and wash again with fairly strong nitric acid, in all cases stirring the while vigorously to expose the surface of the mercury to the cleansing solution.

Before returning the mercury to the break care should be taken to ascertain that the iron pot of the interrupter is quite clean and free from particles of foreign matter that might stop up the jet orifices.

Electrolytic Interrupters.

Electrolytic interrupters may be divided into two classes, the Wehnelt and the Caldwell.

The first consists essentially of a platinum wire protruding slightly from a glass or porcelain sheath immersed in diluted sulphuric acid, this platinum wire constituting the anode. The cathode consists of a lead plate also immersed in the solution, but of comparatively large area (Fig. 141). When this interrupter is connected in series with a coil having a primary winding of ordinary self-induction a series of phenomena are observed. Starting first with a low voltage and at ordinary room temperature the apparatus does not begin to function till the voltage is raised to about 12–14 volts, at which point a thin static spark will pass between the gap points if not too widely separated. At

about 30 to 50 volts we obtain the characteristic Wehnelt discharge, which increases in thickness as the voltage rises. At about 100 volts (depending on the self-induction of the primary) the striking distance of the spark and the value of the primary current begins to decrease, and this continues as the voltage is raised, although the current value of the spark increases. It will be noticed that as the voltage increases so does the

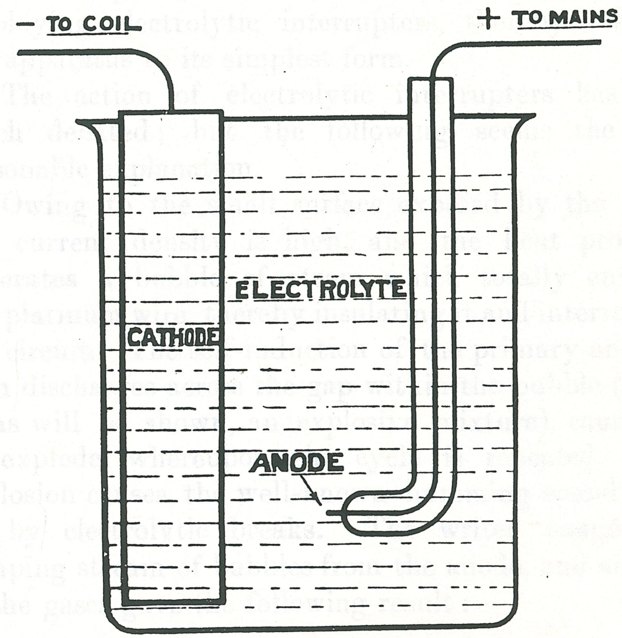


Fig. 141.—Diagram of Wehnelt electrolytic interrupter.

frequency of interruption, hence the decrease in primary current and sparking distance, from which it appears that the spark length varies as the primary current and the milliamperage as the voltage, which is not incompatible with our previous experiences. The writer has succeeded in using voltages as high as 400, at which pressure the frequency becoming very high gives off a shrill note.

At these frequencies the core became very hot and core wires of 30 gauge had to be substituted.

After the interrupter has been in use some time the electrolyte heats up and when a temperature of 75° C. is attained it ceases to work. The acid must then be allowed to cool or fresh cool acid substituted. In the foregoing example nothing but the applied voltage was varied, and we may now consider the effect of varying other factors. Firstly, we noticed the spark length fell off at a certain point, this being due to the fixed self-induction of the coil, hence the primary windings of coils must be carefully chosen for the voltage (and to a lesser degree the current) on which the coil is to be worked. Secondly, on a given fixed voltage, the current rises with an increase of anode surface, but the periodicity falls. Thirdly, with a given anode surface and fixed voltage the periodicity increases as the self-induction is reduced. Coils having a fixed primary winding of low self-induction can frequently be improved by connecting a solenoid with a movable core in series, the core being withdrawn till the best adjustment is reached. With coils having a fixed primary of too high self-induction an improvement can often be effected by connecting two interrupters in series, taking care that the same area of anode surface is exposed in each when they will operate synchronously and in step with a considerable improvement in the secondary sparking distance.

We have said that, other conditions being fixed, an increase of anode surface decreases the periodicity. This is true of one anode, but if two or more smaller anodes are connected in parallel, care being taken that similar areas of platinum are exposed in each, the frequency of interruption will not be decreased.

Summing up, the current passed depends on the area of anode surface exposed, the self-induction and resistance in circuit, and the applied voltage. The

frequency increases with the applied voltage, and becomes greater as the anode size is decreased, and also as the self-induction of the circuit is reduced.

Generally speaking, one fails to obtain the normal spark length of any coil when using electrolytic interrupters, unless special primaries and large currents are used; on the other hand, the heavy secondary discharges obtained counterbalance this defect; moreover, we are able to dispense with the use of a condenser when employing electrolytic interrupters, thereby reducing the apparatus to its simplest form.

The action of electrolytic interrupters has been much debated; but the following seems the most reasonable explanation.

Owing to the small surface exposed by the anode the current density is high, and the heat produced generates a bubble of steam which totally envelops the platinum wire, thereby insulating it and interrupting the circuit. The self-induction of the primary and core then discharges across the gap within the bubble (which is, as will be shown, an explosive mixture), causing it to explode, whereupon the cycle is repeated. This explosion causes the well-known humming sound given off by electrolytic breaks. The writer caught the escaping stream of bubbles from the anode, and analysis of the gases gave the following result:—

Hydrogen . .	60·5	per cent. volume
Oxygen . .	39·5	

and the cathode gases

Hydrogen . .	95·43	per cent. volume
Oxygen . .	4·57	

the percentage of oxygen at the cathode may be due to the action of the induced current of the coil at break as before explained.

For practical purposes the Wehnelt interrupter

takes the forms shown in Figs. 142 and 143. The first consists of a vessel containing the electrolyte, the

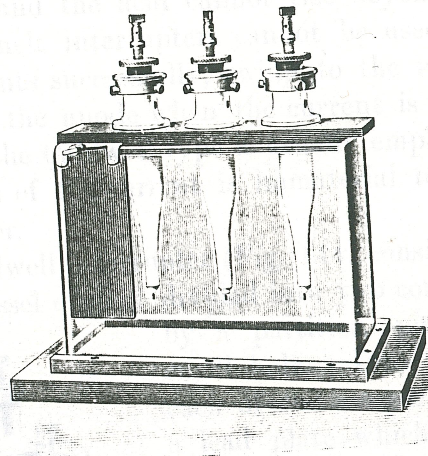


Fig. 142.—View of Wehnelt electrolytic interrupter.

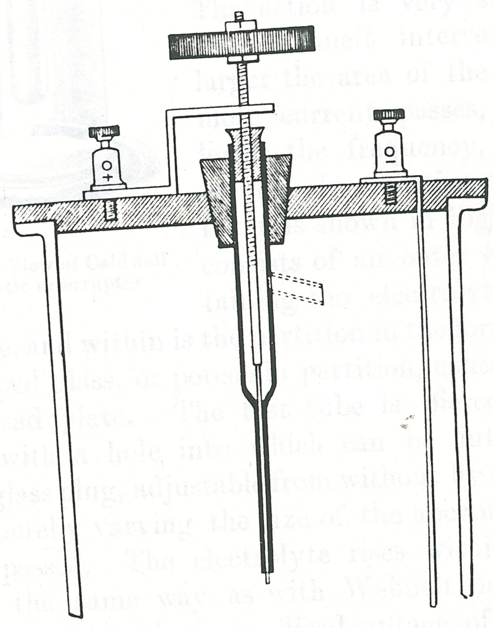


Fig. 143.—Section of Wehnelt electrolytic interrupter, with glass sleeve.

cathode, and the anode, which is a platinum point

protruding through a sheath of porcelain. This platinum point is capable of adjustment by a threaded rod, and bearing a milled head, so that by screwing up or down more or less platinum surface is exposed and the current varied. Fig. 143 is a similar arrangement, but the sheath consists of glass. Usually the intense reaction of the explosions at the anode result in a rise of the electrolyte within the sheath, and in most forms of

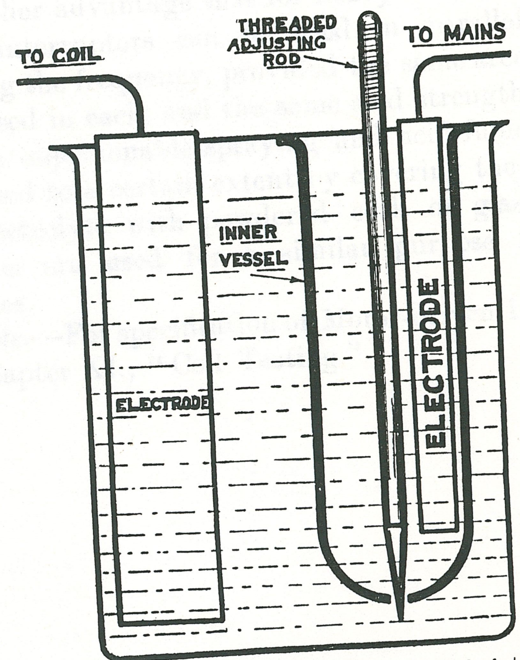


Fig. 144.—Diagram of Caldwell electrolytic interrupter.

interrupter a small spout is provided to allow the acid to flow back into the main vessel.

If the pressure used is at all high (over 100 volts) care must be taken or an explosion will result, owing to the gases in the vessel being fired by the small spark resulting from this returning stream of acid rejoining the main body of electrolyte, thereby short-circuiting the action at the anode. On this account the glass

form of interrupter is to be preferred, as the top of the sheath, being sealed by a gland, the gas therein is compressed, and the acid cannot rise beyond a certain limit. Wehnelt interrupters cannot be used on alternating currents successfully, owing to the rapid disintegration of the anode when the current is reversed in sign, hence the Caldwell type is usually employed, since the direction of the current is immaterial to this form of interrupter.

The Caldwell Interrupter (Fig. 144) consists essentially of a vessel of acid divided into two compartments by a partition pierced by a small hole. Into the acid of each of the compartments dips a lead plate which forms the anode and cathode respectively. The action is very similar to the Wehnelt interrupter, the larger the area of the hole the more current passes, and the lower the frequency, and *vice versâ*. In practice the form taken is shown in Fig. 145. It consists of an outer vessel containing the electrolyte and one lead plate, and within is the partition in the form of a test tube-shaped glass, or porcelain partition, containing the second lead plate. The test tube is pierced at the bottom with a hole into which can be introduced a conical glass plug, adjustable from without by a threaded screw, thereby varying the size of the aperture and the current passed. The electrolyte rises within the test tube in the same way as with Wehnelt interrupters, and is subject to the same disadvantage of explosion, owing to the drip of the overflow acid short-circuiting the true seat of interruption.

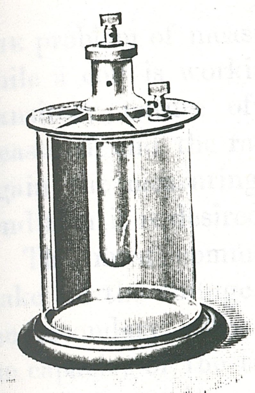


FIG. 145.—View of Caldwell electrolytic interrupter.

Generally speaking, electrolytic interrupters are very reliable, and give extraordinarily consistent results (see Curves, Nos. 45 and 46, p. 32), moreover, they are cheap, and easy to maintain.

The difficulty of overheating may be overcome by using large receptacles for the electrolyte, or, better, by using two or more interrupters, which can be used successively as fatigue sets in. This arrangement has the further advantage that for heavy work two, or even three, interrupters can be used in parallel without lowering the frequency, provided the same area of anode is exposed in each, and the same acid strength used.

The objectionable spraying and acid fumes may be mitigated to a certain extent by covering the surface of the electrolyte with powdered cork or glass bubbles, such as are used for a similar purpose in storage batteries.

Note.—For specification of Motor-driven Interrupter see Chapter XI., "Coil Testing."

CHAPTER IX.

MEASURING INSTRUMENTS AND TESTING.

The problem of measuring the phenomena taking place while a coil is working is most difficult owing to the transitory nature of the conditions required to be measured, and the rapidity with which they die away. Again, the measuring apparatus itself may destroy the condition it is desired to measure.

The most common measurements we require to make are the voltage and amperage in the primary and the secondary. To this can be added less frequently the capacity of the condenser and the self-induction of the primary and secondary.

It is a common fallacy to suppose that any commercial voltmeter or ammeter can be inserted in the coil circuit to obtain a reliable reading, but it must be remembered that the current in a coil is a unidirectional interrupted one, more approximating to a pulsating current than to a continuous one.

On this account it may be as well to reconsider the measurement of alternating current of pure sine wave form A, B, C (Fig. 146), the line AXC representing zero and XB the maximum height of the ordinates or peak value. Now, by drawing a number of lines equidistant from BX and taking their average height, we obtain a value which will be found to be ·635 of

BX, this is the arithmetical mean value of the current, as measured by iron instruments.

Alternatively, if we have the mean value of the current stated as ·635, the maximum or peak value will be 1.

Suppose now, that instead of taking the average value of the ordinates as before, we square the ordinates, we shall obtain a curve inside the sine curve (shown dotted).

The shape of this curve depends on the shape of

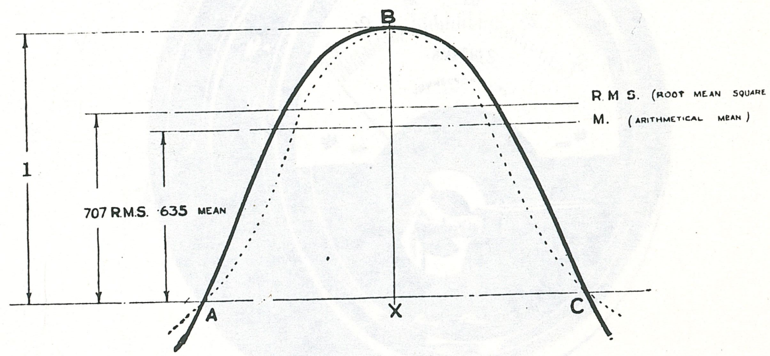


Fig. 146.—Diagram of sine wave and relative values of arithmetic mean and root mean square.

the original curve, and since this curve in coil work is never a sine curve, the shape of the curve of the square of the ordinates will be more or less distorted.

Reverting to the true sine curve, if the square root of the mean value of the ordinates obtained on our new (dotted) curve be taken, they will work out at a higher value than ·635 (the mean value), namely ·707, this is the value of the square root of the mean square, usually called virtual or root mean square (R.M.S.) current or voltage.

Instruments following a "square law," such as electrodynamometers, hot wire and electrostatic instruments, measure the virtual or root mean square value,

that is, if an instrument indicates 70·7, the peak values of the curves will be 100 volts or amperes, or if 100 is read, the peak values will be 141·4 volts, or amperes, as the case may be. In Fig. 147 let A and B represent the two waves, positive and negative of a cycle, and suppose B transferred or folded over as it were to the positive side, we obtain a pulsating rectified current A′B′ somewhat analogous to that obtained from an interrupted current A″B″, as found in a coil circuit, and roughly governed by the same laws, but differing in wave from the true sine curve, not only in natural shape, but depending also on the time economy of

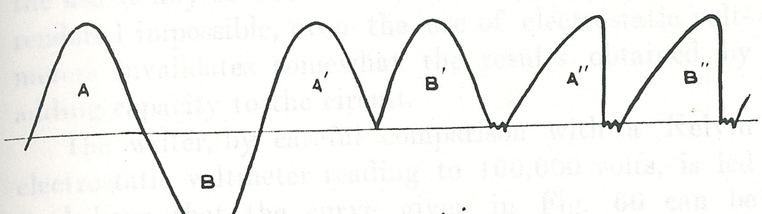


FIG. 147.—Diagram of relation between alternating, rectified and interrupted currents.

the interrupter. Such curves, however, approximate sufficiently to sine curves to enable us to use instruments with a sufficient degree of accuracy for ordinary purposes, provided we know whether the instruments measure the arithmetical mean, such as permanent magnet instruments, or the true R.M.S. values, such as hot wire or electrostatic meters. If a considerable degree of accuracy is desired it will be necessary to obtain oscillograms of the current or voltage and integrate the curve so obtained.

Ammeters (primary current).—*Permanent Magnet* instruments are very frequently used by makers as they are readily obtained. As explained, these read the arithmetical mean of the current.

Hot Wire Instruments (Fig. 148) give more correct

readings as they read the R.M.S. value of the current; moreover, owing to high-frequency effects, the thermal principle on which they work renders them much more accurate indicators of the currents flowing in the primary.

Voltmeters (primary current).—As these are usually used over the mains it is immaterial whether they are

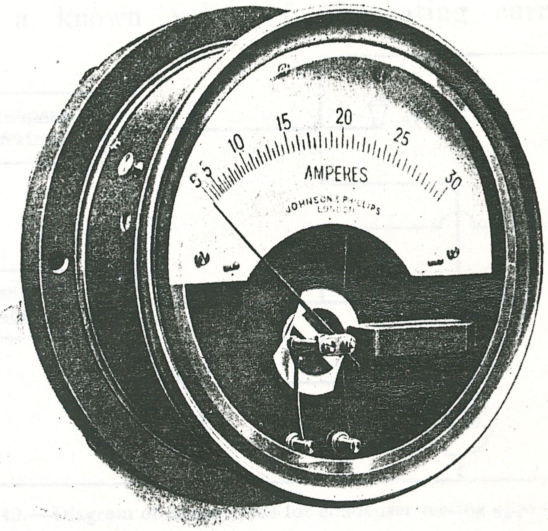


FIG. 148.—Hot wire instrument.

P.M., hot wire, or electrostatic instruments, but, if used directly over the condenser or primary windings, they must be either hot wire or electrostatic, preferably the latter.

Ammeters (secondary current), usually called milli-ammeters (being calibrated in $\frac{1}{1000}$ of an ampere), are generally used. These instruments for X-ray work are nearly always P.M. instruments, as it is difficult to obtain thermal instruments to read the comparatively low current values passed by cathode tubes; moreover, they form an indicator in the event of inverse current

being present by falling to zero or even giving a negative reading. To render these instruments dead beat and to take some account of the high-frequency secondary oscillations, a condenser is usually supplied, shunted over the meter at the back of the instrument, but it is doubtful if such meters are even roughly accurate.

Generally speaking, their readings are of the order of half the true R.M.S. reading of a hot wire or thermal instrument, such as is used for wireless work.

Voltmeters (secondary current).—Owing to the exceedingly small current developed by the secondary the use of any of the more usual forms of voltmeter is rendered impossible, even the use of electrostatic voltmeters invalidates somewhat the results obtained by adding capacity to the circuit.

The writer, by careful comparison with a Kelvin electrostatic voltmeter reading to 100,000 volts, is led to believe that the curve given in Fig. 66 can be relied upon for practical purposes, and therefore the usual method of using an alternative spark gap with needle points, is as good a way as can be desired for everyday use. Provided always, that a spark and not an arc is measured between the points (see p. 52).

For reading the current values in the condenser circuit, hot wire instruments *must* be used, as the current is entirely oscillatory. Even comparatively massive shunts used for the oscillograph readings noticeably decrease the secondary output.

Measurement of Capacity for the primary condensers used for coils may be made sufficiently accurately by the method of direct substitution, the condenser it is desired to measure being compared with a standard condenser of known capacity, by discharging them in turn through a ballistic galvanometer (Fig. 149). The deflections are then proportional to the capacities. If

the condensers are rather small in value, say $\frac{1}{10}$ mfd., it may be necessary to use rather a high voltage, perhaps 50 to 100 volts, and particular care must be taken to insulate thoroughly the keys, etc., used. As most condensers exhibit a current of polarisation due allowance must be made for this, and also when taking the resistance test.

Measurement of Self-induction is best made by passing a known value of alternating current C

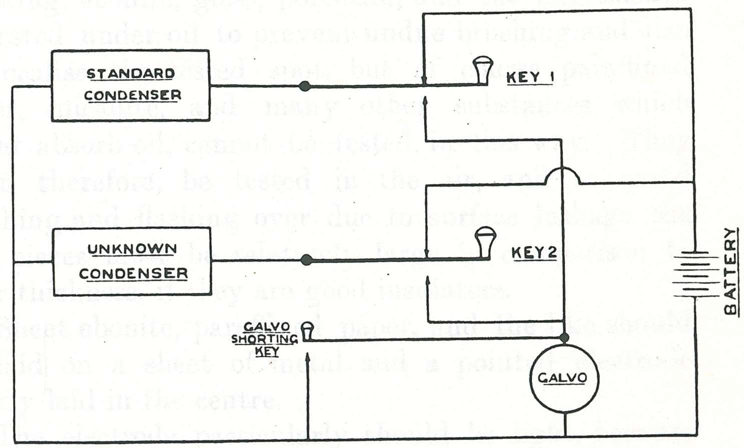


FIG. 149.—Diagram of connections for condenser testing apparatus.

through the primary or secondary to be measured, and noting the pressure E at the terminals, and the frequency N, then if the resistance R of the circuit is low compared to its total impedance, as is the case with most coil primaries and secondaries, R may be neglected, and the self-induction L in henries is given by the formula—

$$L = \frac{E}{2\pi \sim C}$$

In which E = voltage across primary or secondary being tested.

C = current in amperes.

and ~ = frequency in cycles per second.

It must be remembered that the self-induction being a function of the ampere-turns, L is only true with the particular current with which the test is made, care should therefore be taken to employ the same current as that on which coil is to be used in practice.

In order to obtain sufficient pressure to pass a measureable current through the secondary, a transformer (which may be another coil) is necessary, the current being measured by a hot wire milliammeter or other thermal instrument.

Testing Material.

The method of testing material for dielectric strength varies considerably with the substance tested, and therefore it will be better perhaps to select some of the more common materials as examples. It should first be noticed that dielectric strength and insulation resistance are not necessarily the same thing. The general principle governing the test is to arrange the tested material between electrodes and gradually increase the electric stresses, either by direct control, such as when using a transformer, or by using an alternative spark gap, which may be gradually extended in length from zero during the test. This last is the more usual in coil work, as transformers capable of piercing say $\frac{1}{4}''$ of micanite are not usually met with.

Probably an alternating current test would be more severe than the unidirectional interrupted current derived from a coil, since the dielectric is stressed in opposite directions, due to the change in sign of the electromotive force, but for practical purposes the coil test suffices, especially if the coil is large relatively to the test gap required.

When testing, the shapes of the electrodes applied to the material have a considerable bearing on the test, namely whether points or plates. Generally

speaking, it is best to use points, or one point and one plate, as two plates have considerable capacity and lower the effective pressure with any but a large coil or transformer, besides which, the test is not localised but spread over a considerable area. When using a coil for test purposes the alternative gap must be kept sparking, not arcing, so as to obtain the highest pressure obtainable between the electrodes. Generally speaking, ebonite, glass, porcelain, and the like, should be tested under oil to prevent undue brushing and also to localise the tested spot, but of course paraffined paper, micanite, and many other substances which might absorb oil, cannot be tested in this way. They must, therefore, be tested in the air, and to avoid brushing and flashing over due to surface leakage, the test pieces must be relatively large in comparison to their thickness, if they are good insulators.

Sheet ebonite, paraffined paper, and the like should be laid on a sheet of metal and a pointed electrode lightly laid in the centre.

The electrode particularly should be light, because as the test progresses considerable heat may be developed which would allow the electrode to penetrate the substance under test, indeed if this is noticeable the electrode must be fixed in place touching the surface, but unable to move out of position. If it be desired to test the whole surface of the material, a small squeegee of tin-foil with an insulated handle can be substituted for the point, the foil being moved over the whole surface, taking care that the spark does not pass over the edges of the test piece. During the test, it is as well to switch on and off repeatedly, to make sure that the test piece is getting the full benefit of the alternative gap. If the test piece is a tube, a short ring should be slipped in place internally and a single turn of fine wire placed on the exterior in juxtaposition. Sometimes the tube

will be found too short to break down, the spark passing over the edges. This can occasionally be remedied by standing one end of the tube in a saucer of hot paraffin wax and allowing it to set, thereby sealing up one end. The test electrodes should now be moved up towards the sealed end when a further length of spark can be applied. Varnished paper and the like is usually tested by placing the paper between two 2-centimetre balls, and increasing the pressure from a transformer, a voltmeter being substituted for the alternative gap, the maximum voltage before collapse being noted.

Resin, wax and compounds are also sometimes tested in this way, one ball being dipped quickly into the wax to obtain a thin coating of measured thickness, and either a gap or voltmeter used in shunt.

Waxes, however, are better tested by dipping strips of paper into the wax and laying them on the test plate, the point being carefully and lightly adjusted. Of course, the same thickness and quality of paper must be used in each case. The same is true when testing papers, which should be dipped in wax of the same purity and heat, as if the latter varies the paper may be dried to a greater or lesser degree, which has a considerable effect on its dielectric strength. The mean thickness of the waxed paper must be noted with a micrometer, as this varies considerably even in the same sheet, whether testing either the wax or the paper. Not less than three tests on each substance should be made, in order to obtain a mean reading, and abnormal readings should be disregarded. When testing such thin pieces as paper, etc., it is advisable to have the movable electrode of the alternative gap threaded with a fine screw, so that small readings can be taken accurately.

Having carried out the tests the dielectric strength can be worked out for unit thicknesses, and in doing so the thickness of the test piece should not be lost

sight of, more particularly for poor specimens. For instance, if ·5″ of impregnated wood broke down with a 2·5″ spark the resistance to the piercing spark was really only 2″, since there was ·5″ gap between the test electrodes to begin with.

Testing the dielectric strength of oil is carried out in the same way as above described, the test electrodes being well submerged in the oil. It should be noted that the dryness of the oil influences the results obtained, as does the shape of the electrodes themselves.

For coil work two needle points form the best electrodes, as representing more nearly the actual conditions than any other form; results for paraffin oil will be found on p. 227.

One other useful test may be described, that is, the test for surface leakage, such as over the ebonite tubes for secondary barrels, etc. Each end of the tube or sheet under test is coated with a layer of tin-foil, or a turn of lead fuse wire will serve very well, the foils being then connected to the alternative gap, which should be increased till flashing over on the test piece results. This should be considerably in excess of the maximum spark length required to allow for condensation of moisture, etc. With ebonite, any considerable brushing should lead to investigation of the surface for impurities, dirt, or brass dust. Micanite flashes over rather easily, owing to its high surface electrification, and must be covered with varnish, wax, or ebonite, as elsewhere described. This applies, to a lesser extent, to glass, which should be coated with shellac varnish. Generally speaking, the minimum length between the electrodes of the test piece will be found to be not greater than 1·33 times the alternative gap length, thus at least 13″ of ebonite will be required to sustain safely a 10″ spark gap.

CHAPTER X.

COIL MOUNTING AND CONNECTIONS.

Coils are mounted in various ways, depending on the use to which they are to be put, and also on the manufacturer's individual ideas.

An example of the classical form of mounting, substantially as first made by Ruhmkorff in 1851, is shown in Fig. 150, which illustrates a laboratory form

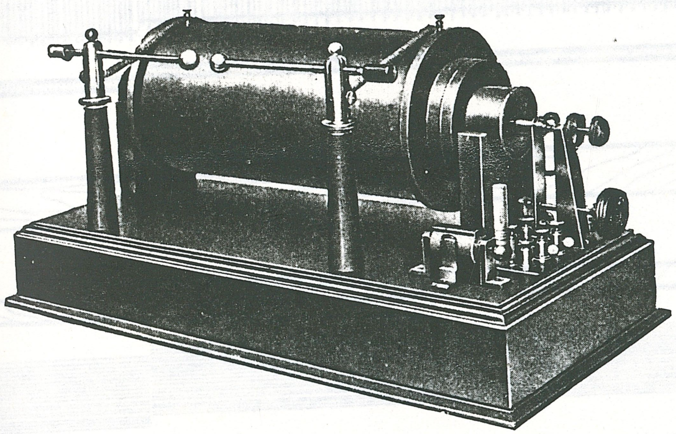


Fig. 150.—Apps type coil.

of coil used for general experimental purposes, and also as an emergency or standby transmitter for wireless by the Admiralty and the Marconi Co. Fig. 151 (Plate VII.) illustrates a sectional view of the same coil. S O S calls are sent by this apparatus with local

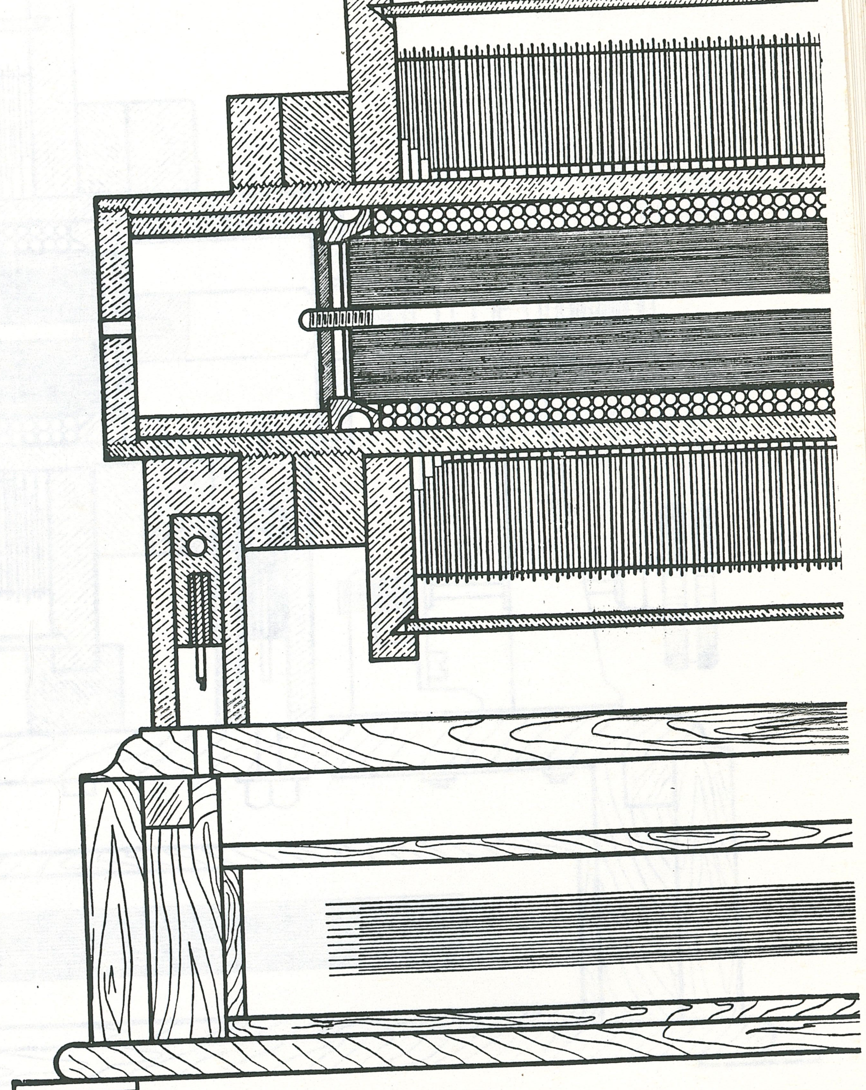
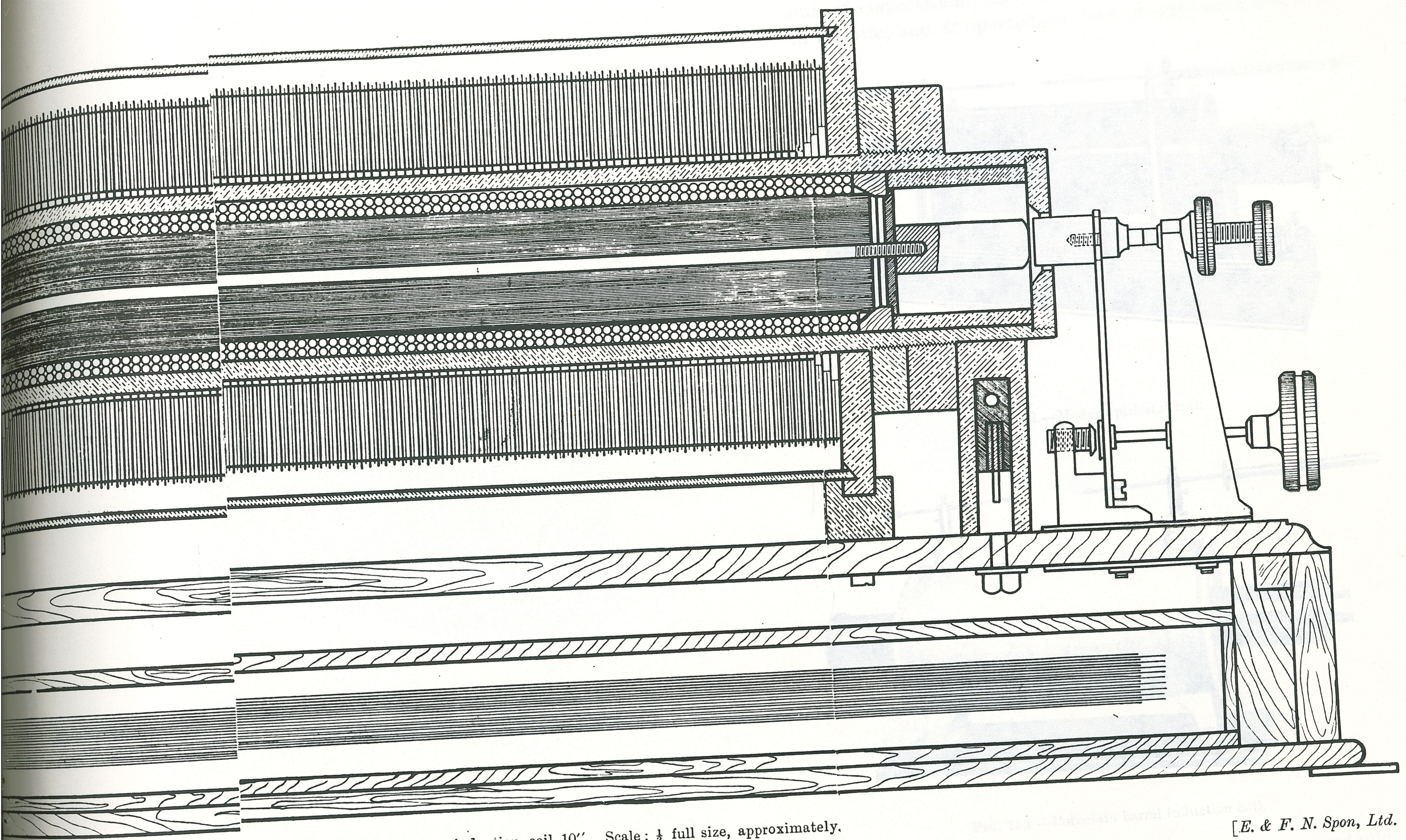


Fig 15

To face p. 184. Codd, "Induction Coil Design."]



ı1.—Section of standard type induction coil 10″. Scale : ½ full size, approximately.

[E. & F. N. Spon, Ltd.

Design."]

batteries, when the main dynamos aboard ship are put out of commission; the bobbin of the coil is sheathed in ebonite, and supported by two ebonite crutches, the

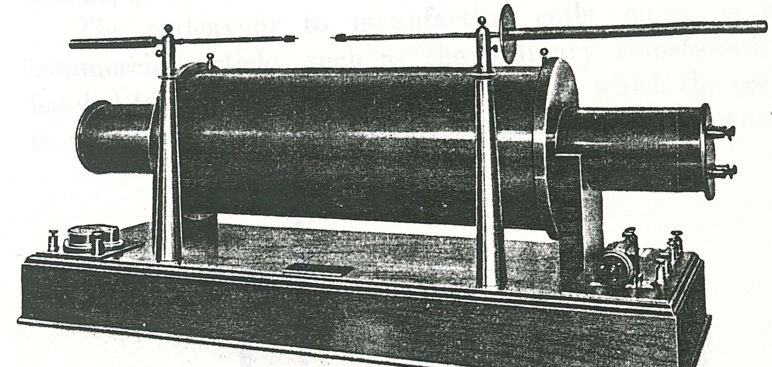


FIG. 152.—Modern pedestal coil.

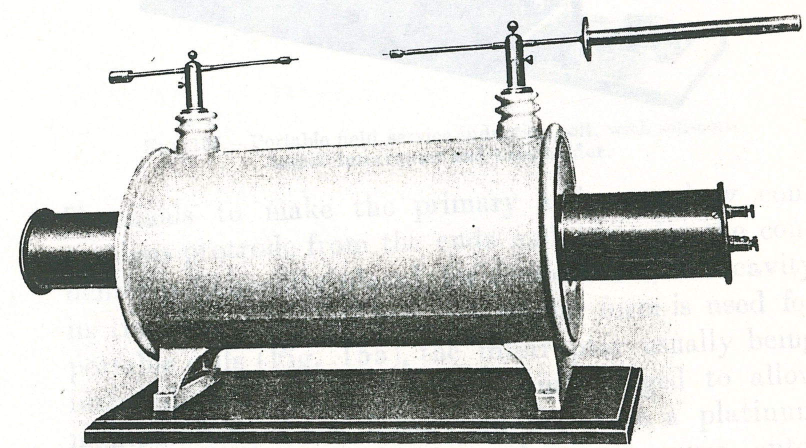


FIG. 153.—Porcelain barrel induction coil.

polished wood base, or pedestal, serving as a receptacle for the condenser.

An Apps platinum interrupter is fitted, with the usual commutator and an arrangement of terminals, so that, if desired, the coil can be worked from the 100-volt mains instead of from the local battery, which is usually of 16 volts.

The more usual form of coil employed for X-ray work is similar in design (Fig. 152), but made without the platinum interrupter, since for heavy continuous work a separate electrolytic or motor-driven interrupter must be used.

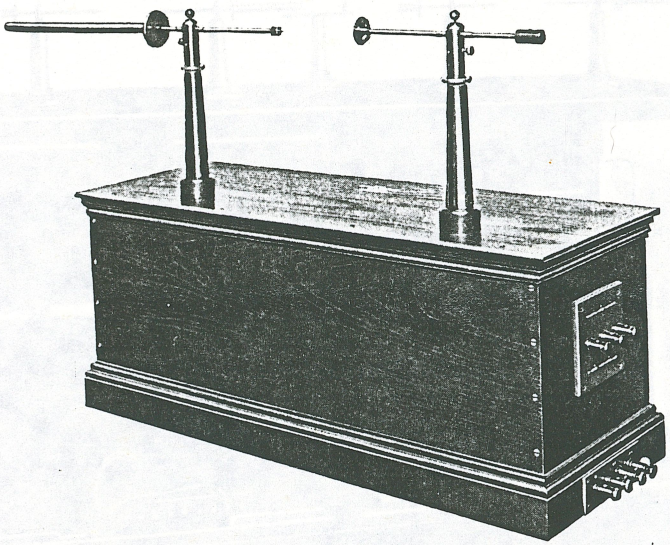


FIG. 154.—Box type modern commercial coil.

As has been pointed out, it is better to locate the condenser as close as possible to the interrupter, and not under the coil base. Fig. 153 depicts a coil of this description finished with porcelain insulation, intended for use with an electrolytic interrupter, or alternatively, with a mercury interrupter having the condenser immediately adjacent.

Frequently it is preferable to mount the coil on brackets fixed to the wall, and for this purpose the

bobbin type of finish is usually employed. This arrangement saves space and removes the coil to a position which minimises the possibility of chance shocks, as the connections, etc., can be run overhead.

The endeavour to manufacture coils more as a commercial article, such as the ordinary transformer, has led to the form shown in Fig. 154, in which the coil is placed in a wooden case and sealed in with wax.

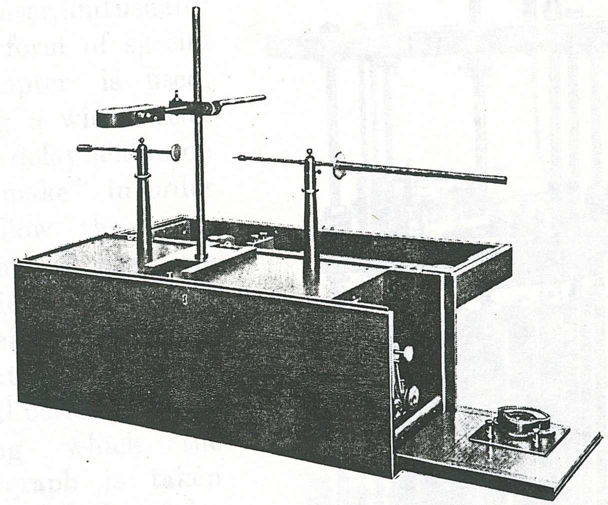


FIG. 155.—Portable field service induction coil, with self-contained interrupter and tube holder.

Terminals to make the primary and secondary connections protrude from the ends and top, also the condenser is frequently placed, for compactness, in a cavity in the base of the coil box. A similar form is used for portable coils (Fig. 155), the interrupter usually being included, one end of the case being hinged to allow manipulation of the break; in this case a platinum interrupter, but more frequently a mercury auto-interrupter is used, similar to that shown in Fig. 134. A similar construction is almost invariably used for mounting small coils for ignition work, and also coils for use in wireless telegraphy.

Single Flash Coils.

These coils (Fig. 156) are simply very large coils capable of taking radiographs through the human body in a single flash, in order that the movement of the heart shall not cause a blurred or double image on the photographic plate, as might happen were two or more interruptions given successively, however rapid.

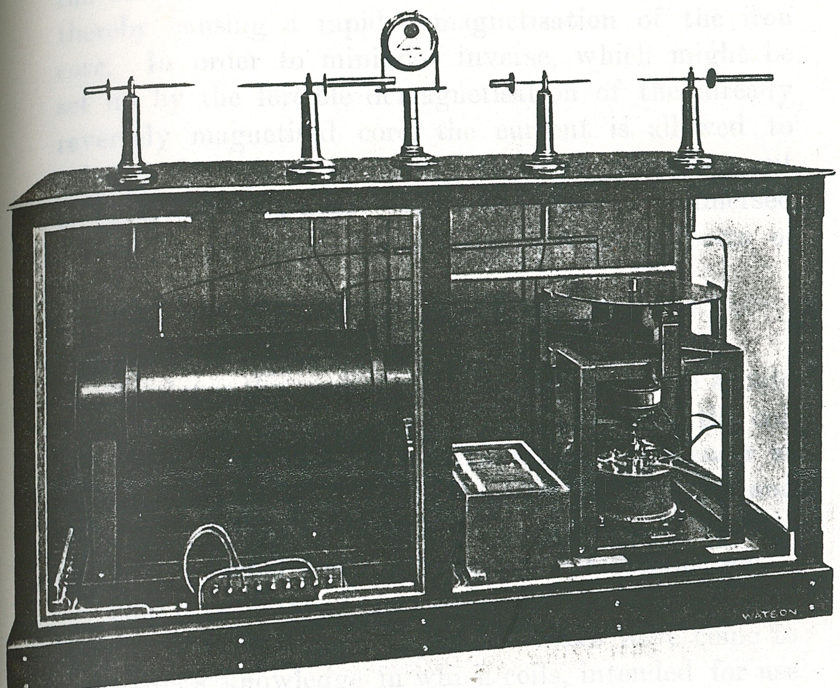


Fig. 156.—Single flash coil.

In order to obtain the desired result, such coils have very massive cores, and the primaries are designed to be able fully to magnetise them. As the fact of a high self-induction does not militate against their efficient action, it is economical to wind the primary with a comparatively large number of turns, so as to take full

advantage of the pressure afforded by the mains, and thereby cut down the current as much as possible; in fact, to obtain the necessary ampere turns by a greater number of turns and less current than would be desirable in normal running conditions. Owing to the tremendous self-inductive voltage, the primary has to be very carefully insulated, as does the condenser, and usually some form of special interrupter is used, giving a wide break and a delay action on the "make" in order to allow the magnetism of the core sufficiently to build up before the current is interrupted. The actual period of break during which the radiograph is taken is only of the order of $\frac{1}{1000}$ of a second, although the stored energy in the iron possibly takes longer than this to die down, hence statements that radiographs are taken in $\frac{1}{50}$ second are misleading unless we comprehend an ordinary interrupter to be used, and several succeeding flashes to be taken, lasting together $\frac{1}{50}$ of a second, as is often the case with so-called single flash coils.

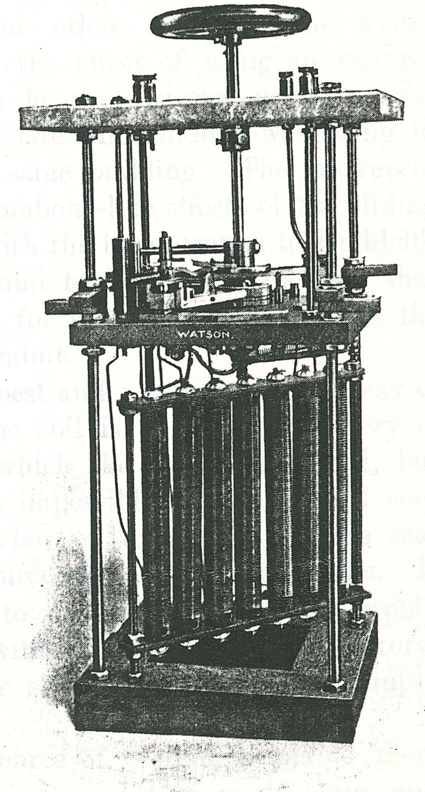


Fig. 157.—Single flash switch and interrupter.

In the coil illustrated the terminals for making

various arrangements of the primary layers can be observed under the coil, and to the right the usual mercury interrupter for general work, coupled to a commutator rectifying-disc apparatus to eliminate inverse.

The single flash interrupter switch for this coil is shown in Fig. 157. It consists of a hand wheel which, when turned, trips an arm, this arm first making contact through the primary in one direction and then interrupts the current and makes contact in the reverse direction, thereby causing a rapid demagnetisation of the iron core. In order to minimise inverse, which might be set up by the forcible demagnetisation of the already reversely magnetised core, the current is allowed to subside through an increasing series of resistances cut in by the rotating arm. The whole device is immersed in paraffin oil to subdue sparking and for purposes of cooling.

Connections.

Whatever the type of coil decided upon, care should be taken to make the length of leads between the coil and interrupter, and the interrupter and condenser as *short, stout and direct* as possible. Leads running to and from the coil, etc., should be laid closely side by side or lightly twisted together to minimise self-induction.

This is of extreme importance even in quite small coils used with portable batteries. Cases have come to the writer's knowledge in which coils, intended for use for wireless purposes, entirely refused to work owing to the length of the leads, although in one case these were rectangular copper bars 2″ wide. In the event of the coil being worked directly from the mains, inspection of course cannot be extended under this heading further than the main fuses, but generally speaking the street mains themselves are of such adequate capacity and carry such large currents that the comparatively small

current consumed by the coil appears to become submerged as soon as it reaches the street mains. Wiring intended to supply current for coils should preferably not be run in steel conduit, especially if using an electrolytic interrupter, as the iron may act inductively upon other circuits contained in the same tube, which would be detrimental to the working of the coil, and cause annoyance to users on other circuits. The writer remembers particularly the effect of using an electrolytic break with which he was experimenting, on the talking arc, which the late Mr. Duddell was using in a distant room of the same building. The arc reproduced faithfully the trombone-like effects of the sliding choking coil in series with the break, much to Duddell's annoyance, and was found to be due to the fact that both pairs of leads ran for some distance through the same length of steel conduit.

When possible the best and most economical way of supplying energy to the coil is by using a battery of the right voltage for which the coil is designed, but very frequently this is impossible owing to local conditions, or from the view of expense, in which case the most convenient source of power is the mains. It is not proposed here to deal with alternating supply systems, as these are, without exception, unsatisfactory, and a motor generator should be installed to supply continuous current.

Having now our source of current available there are two systems of connection open to us, the shunt and the series. The shunt system (Fig. 158) is simply a potentiometer arrangement in which a large resistance, sufficient to carry up to, say 30 amperes, is connected directly across the mains, and the coil and interrupter circuit is arranged to take a bite out of this resistance, thereby shunting it, more or less, according to where the current is picked off by the sliding contact. This

arrangement gives a large number of gradations, from zero to the full main voltage, but is very wasteful, in that a large current is flowing all the time, independent of the coil current which may be very small or even

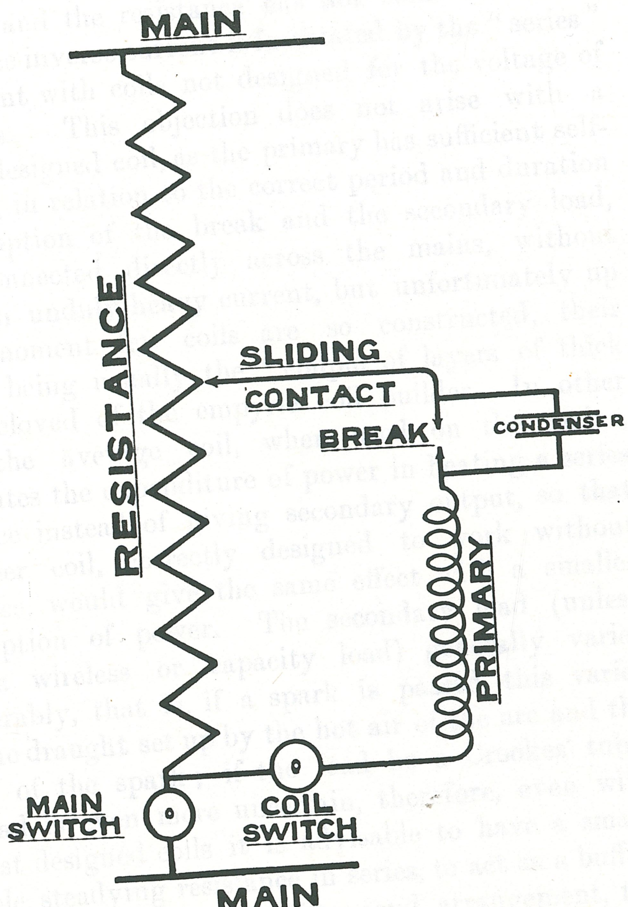


FIG. 158.—Diagram of shunt arrangement of coil connections

zero. This method is chiefly useful where the coil has not been designed for the pressure of the circuit at hand, and for coils suitably made the series arrangement should be used, both on the grounds of simplicity and

economy (Fig. 159). Here we have the coil and interrupter in series, with a resistance directly across the mains, the same current flowing in the coil, resistance and interrupter, this current being directly variable by

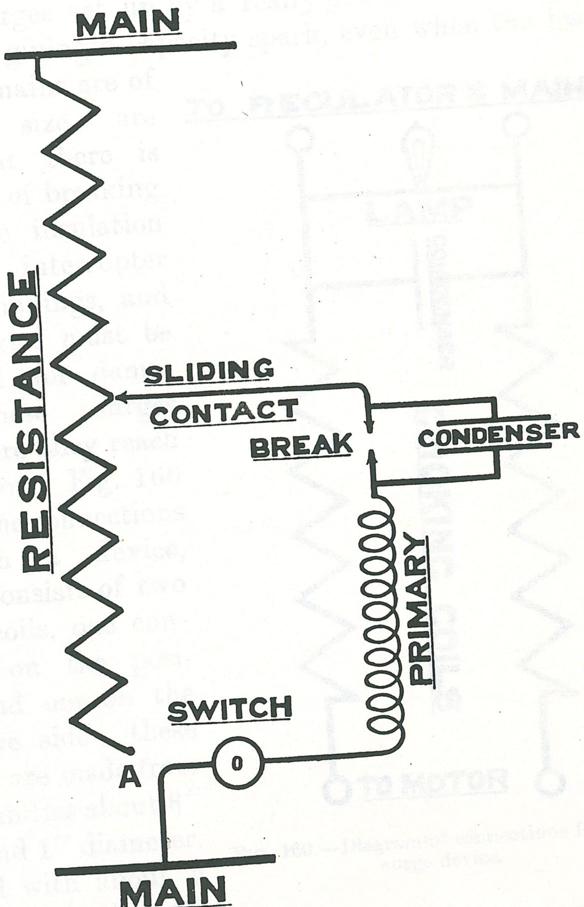


FIG. 159.—Diagram of series arrangement of coil connections.

means of the resistance. This arrangement is much more economical, but it should be noticed that with a coil having an insufficient primary the "shunt" arrangement is best for X-ray work, in that the minimum

voltage only with which it will work is applied to it, whereas when working with the "series" arrangement, although, when the circuit is closed the applied voltage is correct, at the moment contact first takes place the voltage is that of the mains, since only a small current is flowing and the resistance has not come to its full value, hence inverse current is facilitated by the "series" arrangement with coils not designed for the voltage of the mains. This objection does not arise with a correctly designed coil, as the primary has sufficient self-induction, in relation to the correct period and duration of interruption of the break and the secondary load, to be connected directly across the mains, without taking an unduly heavy current, but unfortunately up to the moment few coils are so constructed, their primary being usually the "couple of layers of thick wire" beloved of the empyric coil builder. In other words the average coil, when used on the mains, necessitates the expenditure of power in heating a series resistance instead of giving secondary output, so that a smaller coil, correctly designed to work without resistance, would give the same effect with a smaller consumption of power. The secondary load (unless it is a wireless or capacity load) generally varies considerably, that is, if a spark is passed, this varies with the draught set up by the hot air of the arc and the length of the spark; if the load be a Crookes' tube, the load is even more uncertain, therefore, even with the best designed coils it is advisable to have a small, variable, steadying resistance in series, to act as a buffer. It will be noticed that in this second arrangement, the addition of a connection at A will give virtually the same arrangement as in Fig. 158. In practice the connection at A is a switch, so that either the series or parallel arrangement can be used at will, the resistance being so proportioned as to permit of this

alternative connection being made. In passing, it should be mentioned that the resistance used should have a slate, porcelain or air core, and not be wound on an iron or metal frame, or else considerable self-induction is introduced.

The surges set up by a really powerful coil, especially when giving a capacity spark, even when the leads from the mains are of adequate size, are such, that there is great risk of breaking down the insulation of the interrupter motor windings, and some device must be arranged for damping these surges out before they reach the motor. Fig. 160 shows the connections of such a device, which consists of two choke coils, one connected on the positive, and one on the negative side; these chokes are made from iron bundles about 8″ long and 1″ diameter, wound with about 5 layers of No. 20 D.C.C. wire. A small condenser of about 1 mfd. capacity is shunted across the ends remote from the motor, and, as an additional safeguard, a 16 c.p. carbon lamp is connected in parallel with the condenser. This also serves as a pilot lamp, and shows roughly the

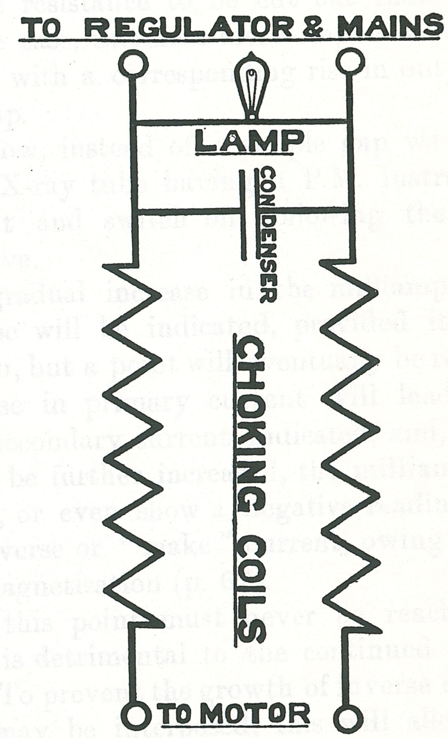


FIG. 160.—Diagram of connections for anti-surge device.

motor speed by its degree of illumination. The effect of this arrangement is that the inductances choke back the surges set up by the coil, which prefer to enter the condenser and escape by the lamp, rather than surmount the self-induction of the cores and burn out the motor. Whatever precautions of this nature may be taken, however, it is of the utmost importance that the insulation of the motor itself be of the highest order, say not less than 5 megohms from winding to frame; moreover, the motor frame must be well insulated from the iron pot of the interrupter (say 50 megohms), as it will be remembered that the pot itself is in contact with the current-carrying mercury. Besides using first-class insulation, the frame of the motor should not approach the mercury pot by a less distance than ½″ when using a powerful coil, as the inductive kick of the primary may leap this distance through the air over the surface of the insulation.

Manipulation.

The whole apparatus being set up, and everything being to the operator's satisfaction, the interrupter should be started. The speed of interruption is rarely stated for any coil, but a speed of 50 periods per second is a good average value. The contact segment, when variable, should be set at the least contact length, and the resistance should be all in. Set the spark dischargers at the required distance, say half the maximum spark length, and switch on. Usually a thin weedy spark will result, and the contact segment should be lowered till a small regular spark results at the gap. Resistance should now be cut out, till, if the coil is well designed for the voltage employed, the coil will now be running direct on the mains. Next cut in a little resistance to act as a steady, and further depress the contact segments, till the output desired is obtained from the secondary.

A point will probably be observed at which an increase in primary current does not give a corresponding increase in secondary output, because the iron core is saturated.

The speed of the interrupter may now be varied to ascertain the effect on the secondary discharge. If the coil is of rather low self-induction an increase in speed will enable more resistance to be cut out than would otherwise be the case, therefore more impulses will be given per second with a corresponding rise in output at the secondary gap.

Supposing now, instead of a simple gap we shunt the gap by an X-ray tube having a P.M. instrument in series with it and switch on, following the same procedure as above.

At first a gradual increase in the milliampereage through the tube will be indicated, provided it is in suitable condition, but a point will eventually be reached when an increase in primary current will lead to a decrease in the secondary current indicated, and, if the primary current be further increased, the milliammeter will fall to zero, or even show a negative reading, this being due to inverse or "make" current, owing to the forcing of the magnetisation (p. 67).

In practice this point must never be reached, as inverse current is detrimental to the continued usefulness of tubes. To prevent the growth of inverse current a valve tube may be interposed, this will allow the direct current in the tube to be further increased. Generally speaking, however, the presence of inverse current is a sign that the coil is being used on a voltage too high for the design of the primary, or that the coil is being forced beyond its economical point, the remedy being, either a different primary containing more turns, or else a more powerful coil. Raising the speed in cases like this does not help matters, as the increased

impulses due to a higher periodicity per second tend to heat up the tube (the period of rest being relatively shortened), which still further lowers the vacuum and increases the growth of inverse current.

Platinum interrupters give no such scope for adjustment and their results are relatively less efficient. It is necessary to employ cells of the correct voltage for which the coils are designed, as coils with platinum breaks cannot be worked directly off the mains. There is little to do with the usual form of break, beyond adjusting the platinum screw and tension screws, to obtain fortuitously the best results, and then seeing that the contacts are kept clean and unpitted.

The battery should occasionally be reversed through the break in order to minimise pitting of the platinum.

When, however, the platinum shows signs of pitting the surfaces should be trimmed up with emery paper or a fine file. This should be done before the pitting becomes excessive, or else a considerable amount of platinum may have to be removed.

CHAPTER XI.

COIL TESTING.

In order to test a coil thoroughly it is desirable to obtain from the makers, if possible, the necessary constants. These include the resistance of the primary, the resistance of the secondary, the number of turns of primary, the number of turns of the secondary, and the capacity of the condenser. The readings of resistance and capacity should be verified before the coil is put into commission, and before it has become warmed up by passing current. In the event of the coil partly breaking down at any time, the values of the resistances offer useful guides as to where the failure has taken place. Knowing the number of turns in the primary and secondary enables one to check the transformation ratios with a practical test on alternating current, using one or more layers of primary.

If another coil of equal power is available, interesting back-to-back tests can be made and the self-induction of the secondary and overall efficiency measured. Before the coil is run on the mains, the above data should be noted for future reference, together with the insulation resistance of the primary from the core, the primary from the secondary, and the capacity and insulation resistance of the condenser.

The coil may now be connected up with its interrupter and tried for maximum length of spark. This

however, should not be continued longer than is necessary, as, however good the insulation of the coil, it is never advisable to use a larger length of spark than circumstances demand, or idly to extend the discharger rods to see how much the coil will stand, when once it has been tested and passed.

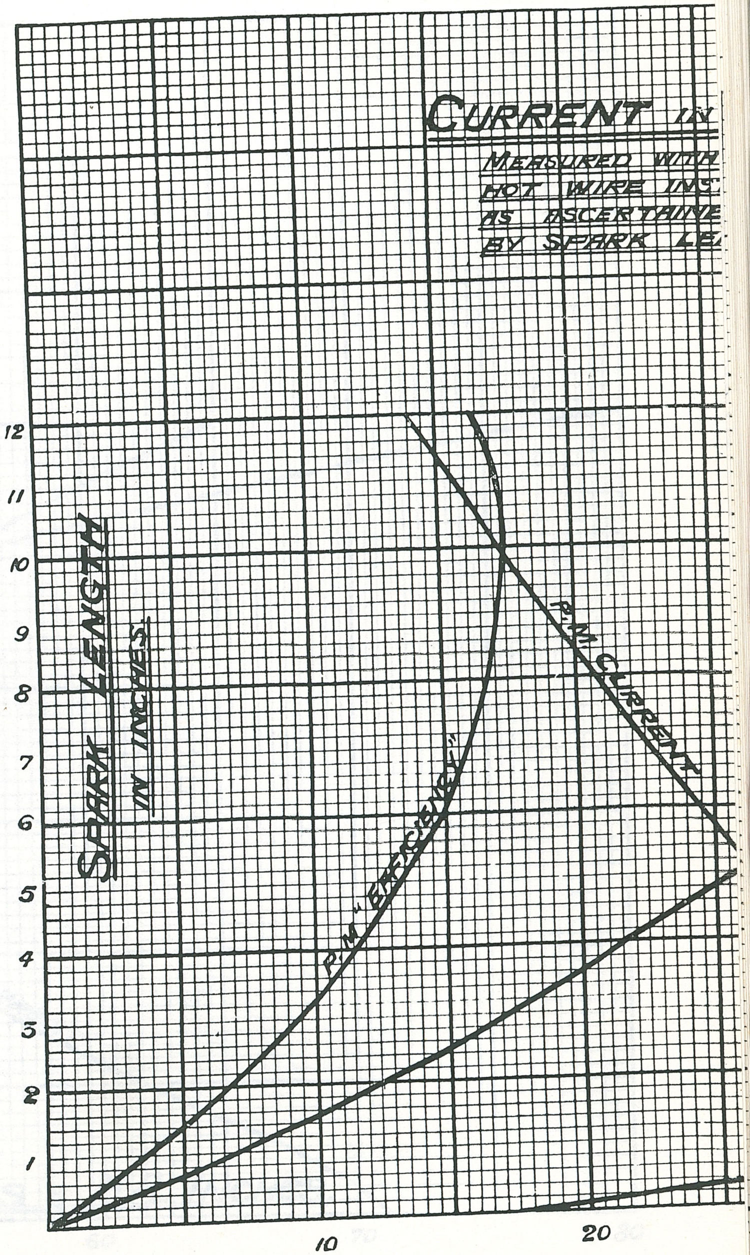
The usual spark test consists in fully extending the discharger rods and passing maximum current through the coil for some minutes, then the interrupter is gradually slowed till it stops. This subjects the coil to maximum strain at any periodicity and when once the coil has passed the test, this should not be needlessly repeated.

Good coils should stand the test of earthing either end of the secondary and extending the sparking length to half the maximum rated discharge length, but this test should not be carried out unless the makers agree that the coil be so tested. The breakdown test being finished, tests may be made for secondary discharge through spark gaps in air, the necessary milliammeters being in circuit.

Very interesting curves can be obtained in this way by plotting the characteristics of the coil in milliampere output, against spark length in inches.

Figs. 161 (Plate VIII.) and 162 (Plate IX.) show two such characteristic curves, both being for 12″ coils. Fig. 161 being a small coil with core 24″ long and 2″ diameter, and Fig. 162 a large one having a core 36″ long and 4″ diameter, being really a 16″ coil limited to a 12″ discharge.

In these tests the current in the primary and the speed of interruptions and time economy were kept constant, the current being regulated by a series resistance. Both oil and gas interrupters were tried, but no material difference was noticeable. The currents given in the H.W. and P.W. instruments form some guide as



To face p. 200. Codd, "Induction Coil Design."]

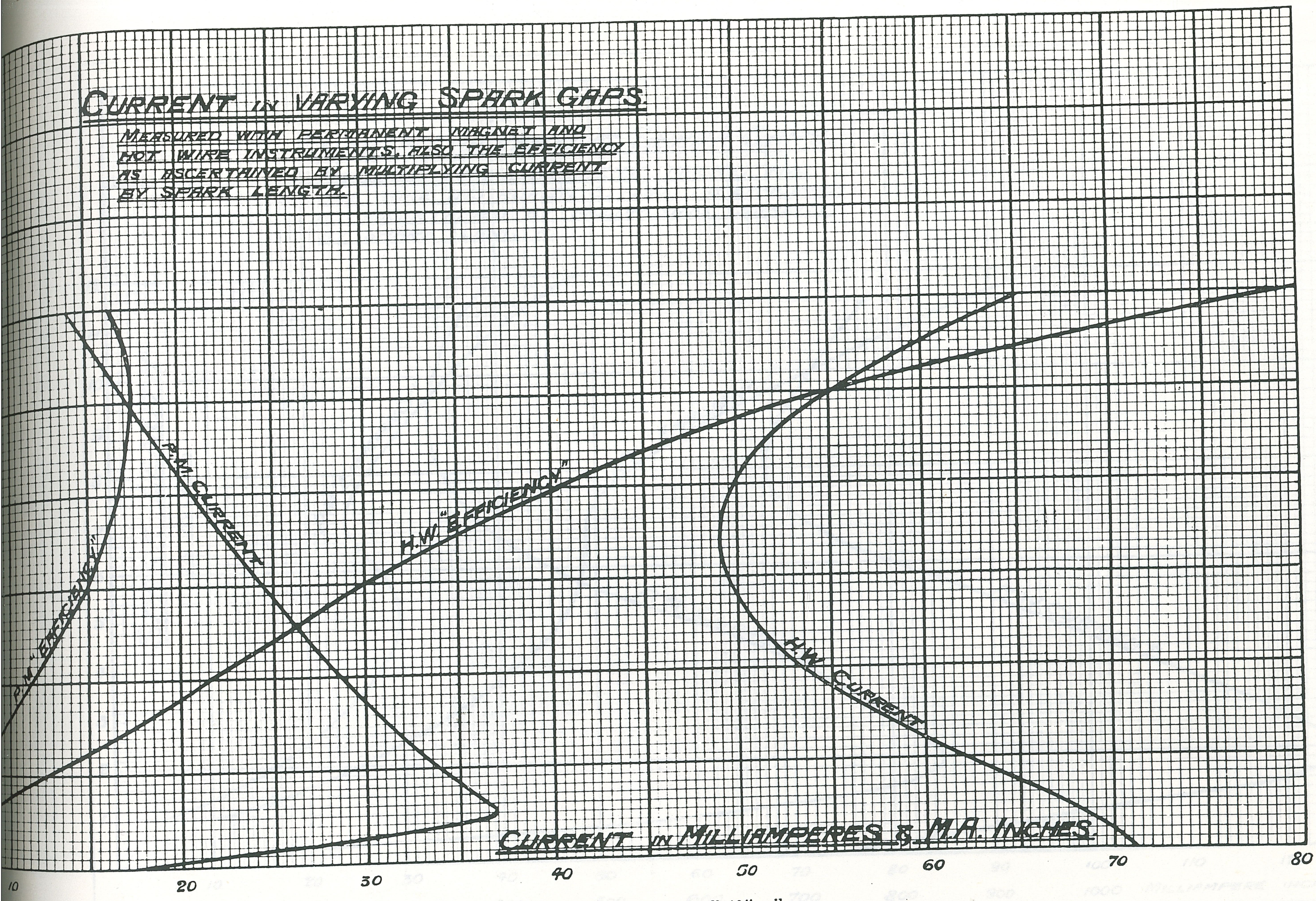


FIG. 161.—Characteristic of secondary output of small 12″ coil.

[E. & F. N. Spon, Ltd.

...duction Coil Design."]

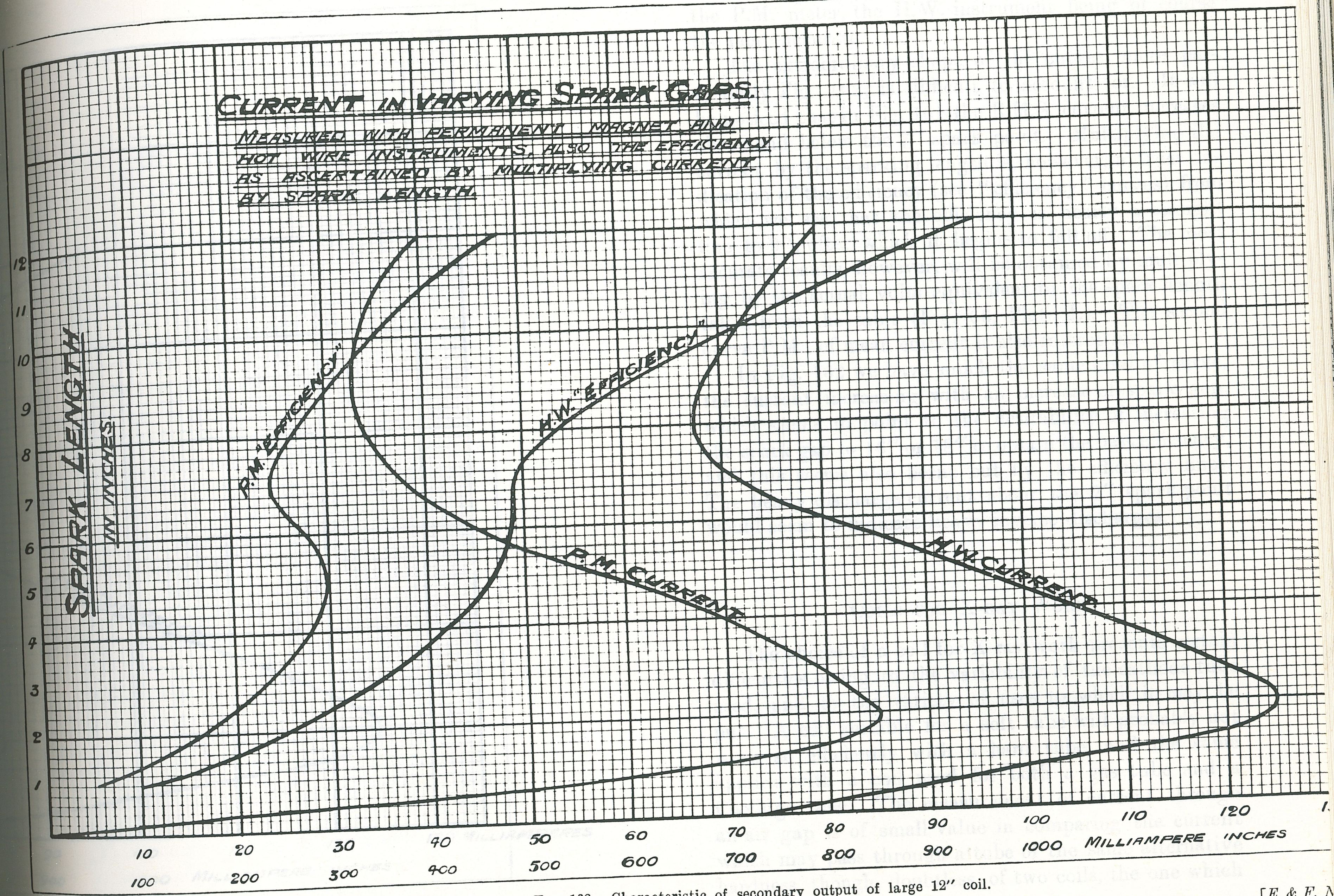
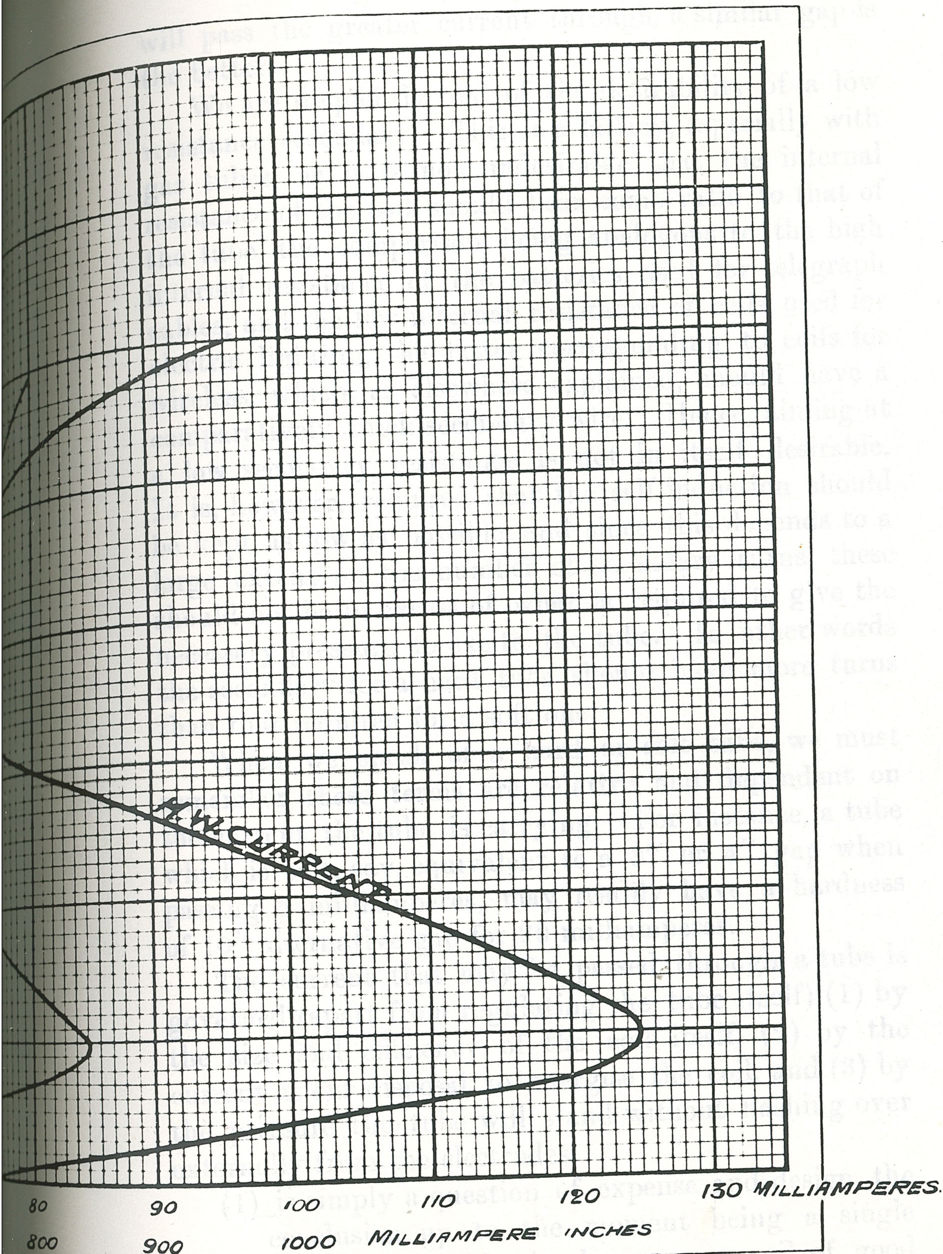


FIG. 162.—Characteristic of secondary output of large 12″ coil.

[E. & F. N

To face p. 201. Coull, "Induction Coil Design."]

PLATE IX.



...y output of large 12″ coil.

[E. & F. N. Spon, Ltd.

to the errors which occur in practice through the use of the P.M. meter, the H.W. instrument being of course the more accurate.

The extraordinary shape of the curves, more particularly Fig. 162, is difficult to account for. It will be noticed that in Fig. 161 the R.M.S. current increases above and below the 7″ spark point. Multiplying the current by the sparking length is, however, a truer indication of the efficiency (see "efficiency" curves) from which we see that the efficiency is nearly a straight line to 9″, after which it begins to fall off. The most accurate results, however, will be obtained by multiplying by the actual volts equivalent to the spark length taken from the table (Fig. 66, Plate I.). The second curve P.M., of mean current is also interesting.

In Fig. 162 we have much the same kind of curve, the current increasing with an increase of spark gap, which seems to point to the desirability of increasing the spark gap to 16″ or 18″ to obtain the best efficiency, and this seems also borne out by the efficiency lines. The heavy discharge current about the 2″ spark point would seem to indicate heavy inverse discharges.

Coils for X-ray Work.

The choice of a coil for X-ray work presents certain difficulties owing to the variability of the cathode tube used, and to the variety of uses to which it may be put. A coil suitable for a soft tube will probably not work so efficiently with a hard tube, and the same applies with a coil used for both a gas tube and a Coolidge tube. The measurement of current through an air gap is of small value in comparing the current which may pass through a tube of the same alternative hardness, though, doubtless, of two coils, the one which

will pass the greater current through a similar gap is the better.

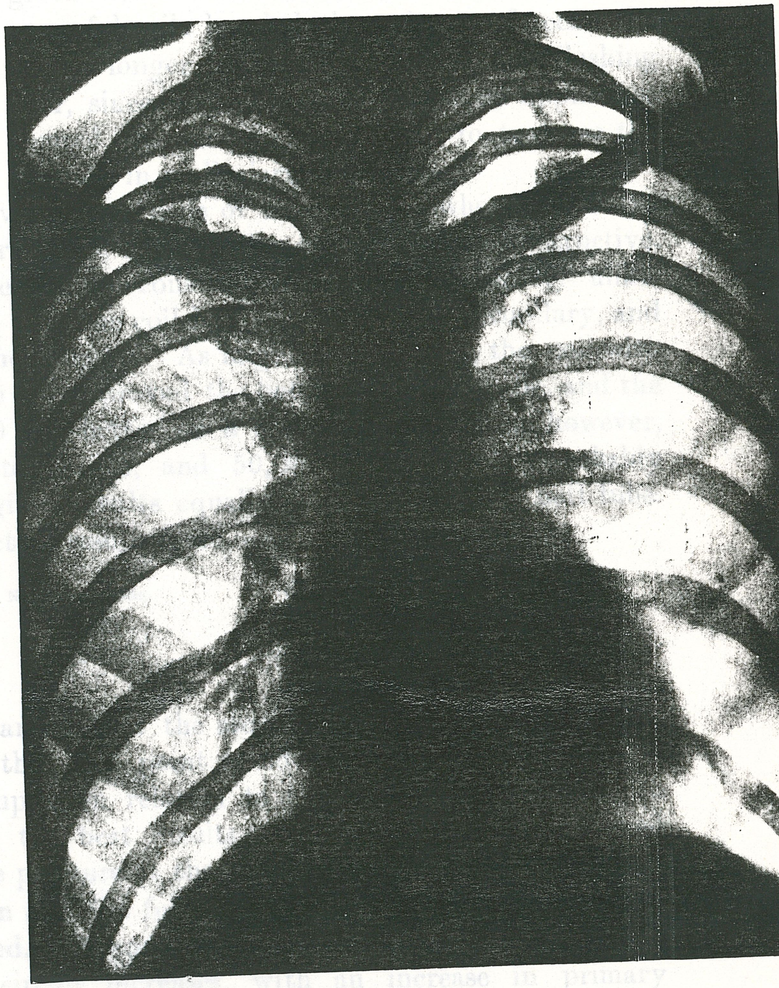
We are frequently told of the desirability of a low resistance secondary. This is a fallacy, especially with gas tubes, as it is not undesirable that the internal resistance of the coil should bear some ratio to that of the tube, the comparison being analogous to the high internal resistance of the batteries used for telegraph cables, and the low internal resistance of cells used for electric lighting, the latter corresponding to coils for wireless, which, as elsewhere explained, should have a comparatively thick secondary wire. Hence, aiming at a low secondary resistance is not in itself desirable. It is, however, required that the self-induction should be kept as low as possible, and since this depends to a large extent on the number of secondary turns, these should not be in excess of what is required to give the necessary pressure to excite the tube. In other words the secondary for a hard tube should have more turns than that required for a soft one.

When we speak of a hard or soft tube, we must remember these terms are relative and dependent on the current the tube is carrying. For instance, a tube which is soft, say, equivalent to a 3″ or 4″ gap when passing 5 milliamperes, may readily have a hardness of 10″ alternative gap for 20 milliamperes.

The current that may be passed through a tube is governed (apart from regulating the tube itself) (1) by the size and efficiency of the coil itself, (2) by the current at our disposal to energise the coil, and (3) by the pressure the tube will stand without flashing over externally from the electrodes.

(1) is simply a question of expense and design, the conclusion up to the moment being a single flash coil, which simply means a coil of good design having an ample magnetic core capable

PLATE IXA.



Normal Chest—adult female. Taken with one of the writer's coils by Dr. R. W. A. Salmond.
Exposure 1 second. 25 Milliamperes.

To face p. 202. Codd, "*Induction Coil Design.*"] [*E. & F. N. Spon, Ltd.*

(2) of absorbing and giving out a large quantity of energy. Hitherto, (3) the use of soft tubes has given little trouble; but the advent of more powerful coils has led the writer to forecast the use of longer tubes, to avoid external flashing over, since large pressures must be applied to compel the unwilling milliamp to traverse the vacuum in really large numbers.

Reverting to coils of normal size when applied to ordinary tubes, the following example may be instructive.

The writer constructed two coils exactly alike, except that one coil had 40,000 turns of secondary, and the other 60,000. As might be expected, the coil with 60,000 turns proved the better on a hard tube, and the 40,000 the better on a soft one; there was, however, little to choose, and 50,000 turns would probably have given results equally good on a hard or soft tube. The actual results were :—

No. of Sec. Turns.	4″ Tube.	6″ Tube.
40,000	35 ma.	15 ma.
60,000	30 ma.	19 ma.

Granted that the secondary is suitable for the tube used, the next point is to examine the primary and interrupter, in relation to the voltage we are using to obtain the best results. Supposing the voltage fixed by the pressure at the mains, we switch on with resistance in and the full surface of the interrupter contacts exposed. On cutting out resistance the current in the tube circuit increases, with an increase in primary current, till no more can be taken for fear of blowing the fuses. This indicates that (1) the interrupter is not running fast enough, (2) there are not enough primary turns on the coil, or alternatively, (3) the contact segments on the interrupter are too long, and giving too small a time economy. The remedy in each

case is obvious; but alterations should be made cautiously, remembering that another tube, especially if a Coolidge, will require a different adjustment.

The current in the tube circuit is usually measured with a P.M. instrument; but whatever meter is used it should be realised that the *current only* is not a true index of the radiographic activity of the tube. This may be proved as follows. The tube under examination (in this case a Coolidge) should be set up in series with the oscillograph, taking as large a current as possible with a medium hardness.

In front of the tube is arranged a sheet-metal slide, similar to that in the oscillograph, down which a photographic plate can be dropped. Near the end of the slide a narrow slot is cut, the slot being as nearly opposite the focus of the tube as possible. The slot is covered with black paper to exclude light. The velocity of the plate can be calculated as it passes the slot, but if the slide is the exact counterpart of that used in the oscillograph this can be neglected. Current is now switched on, and the plates in the oscillograph and in the slide in front of the tube are both dropped simultaneously, with the result shown in oscillographs (Figs. 52, 53). It will be seen that the current in the tube rises to a high peak value for two or three of the super-imposed condenser oscillations, and then dies away more or less gradually. On examining the plate from the tube slide, we find, exactly in synchronism, first a well-defined dark bar, corresponding to the first high peak value of the current, then a second, fainter and partly overlapping, and after that nothing, thus proving that the flat part of the curve is devoid of ray-producing qualities, and serves only to heat the tube, causing a larger deflection of the milliammeter than is justified by the production, or the absence of production of X-rays. The above results are true, but in a lesser

extent, with gas tubes, since the dying away portion is much shorter than with Coolidge tubes.

The part the condenser plays in this experiment should not be lost sight of.

The value of the condenser being fairly large gives two or three oscillations in the secondary, thereby causing several peaks to appear at the initial break, and increasing the radioactivity of the tube. Against this must be set the tailing out of the current curve which serves, as explained, only to heat the tube and give deceptively large readings on the milliammeter. It should therefore be our object, especially with gas tubes, to use as small a condenser as possible, such a size as will cause the coil to work well under the conditions in which we are using it, without destroying the contacts of the interrupter. Since radioactivity is only stimulated by the highest impulses these should be kept short, but as frequent as is possible without overheating the tube, in other words, the interrupter must be speeded up. The current value in the tube which produces the quantity of X-rays must not be confused with the penetration, which is governed by the pressure applied.

As far as the writer has been able to determine, an average fairly hard tube of about 6″ equivalent gap requires a R.M.S. pressure of 50,000 volts to work it well, and a really hard tube about 60,000 volts. It will be realised that the instantaneous initial or striking voltage which breaks down the vacuum is probably two or three times this value.

Taking 50,000 volts as a good average pressure we find that 50 watts are delivered by the secondary for every milliampere read on the meter, thus 10 milliamperes indicate that with a medium tube the secondary is passing 500 watts. Allowing that the efficiency of the coils is 50 per cent. (a high figure for even the best large coils) the primary must be using at least

1,000 watts. Bearing this simple calculation in mind, it is easy to check some of the more extravagant claims made for output with input by some coil manufacturers, in other words current in the tube cannot be obtained without a sufficient expenditure of watts in the primary; that is *in the primary,* not in heating up an external resistance, which still further lowers the efficiency of the whole apparatus.

Reviewing briefly the points desirable in a good coil outfit we conclude that—

1. The secondary should have a sufficiently high transformation ratio to give a good pressure at tube terminals, but should be of as low self-induction as possible.
2. The primary should be capable of running direct off the mains if needed, to avoid C^2R losses in the resistance, this being governed by
3. An interrupter with a correctly designed time economy, and
4. An interrupter which can be run at the highest speed to deliver the greatest number of impulses to the tube without risk of heating it and causing inverse current and fatigue.
5. As small a value of condenser as will give one or two peaky oscillations without burning unduly the contacts of the interrupter.

The following abbreviated specifications and tests may be of interest. The first is that of a 10″ coil suitable for service in India, the second is that drawn up by the Advisory Committee after mutual enquiry with the writer into the requirements of several Departments of the Government, and therefore shows the trend of modern design for X-ray work in coils of standardised spark length, namely, 12″ and 16″ respectively.

SPECIFICATION No. 561B.

Approved January 12th, 1917.

COIL, INDUCTION, 10″, with Variable Primary and Variable Condenser.

PORTABLE "FIELD SERVICE" PATTERN.

1. *Type and Dimensions.*—The coil is to be of the Portable Field Service Pattern, with ball-jointed discharging rods on ebonite pillars and localising slide. A moving coil ammeter is to be fitted on the drop-down flap or inside on the ebonite end plate. The outside dimensions of the polished teak case containing the windings, etc. are to be as follows:—

Length	$25\frac{1}{2}$ inches.
Breadth	$10\frac{1}{2}$,,
Depth	$12\frac{1}{8}$,,

2. *Weight.*—The complete coil and teak case with straps as above is not to exceed 97 lbs. in weight.

3. *Case.*—The windings are to be contained and securely fixed in a polished well-seasoned teak case of the above dimensions. The case is to be free from all flaws and securely fixed together by screws in addition to being glued.

Discharging from the screws must be obviated either by insulation or by the use of tough fibre screws.

The ebonite discharging pillars and plates are to fit in the inside of the lid and to be securely held in transport by means of clips; the tube holder and pillar is to be similarly held.

The interrupter end of case is to have a drop-down flap which is to be held securely by the lid when closed.

A good lever lock of at least two levers is to be provided together with two keys.

The hinges are to be "arrow" butts, fixed with brass screws.

The case is to be dustproof, and the lid and case must be provided with a tongue and groove.

The lid is to be lined with green cloth securely attached by pinned fillets as well as being glued.

4. *Ebonite Top and End.*—The windings are to have an ebonite top and end.

5. *Pillar Sockets.*—Sockets are to be provided in the top ebonite plate to hold the pillars; these sockets form the terminals of the secondary and are to be about 11″ apart.

6. *Pillars and Discharging Rods.*—Ebonite pillars with terminals and also with brass plugs to fit in the above sockets are to be provided. Sliding brass discharging rods with ball joints and ebonite handles are to be mounted on the pillars and electrically connected with the plugs. Two discharging points and two discharging plates are to be provided for attachment to the discharging rods. The rods must be capable of a separation of not less than 10″.

7. *Platinum Contacts.*—To be ·25″ diameter and ·25″ long, neglecting the screwed portion; each contact is to be screwed No. 3 B.A.

8. *Core.*—The core is to consist of a bundle of best charcoal iron wire thoroughly impregnated with some insulating compound to prevent eddy currents.

9. *Primary.*—The primary is to consist of about 700 turns of double cotton-covered copper wire, 15 S.W.G., well insulated from the core. The primary is to be variable with two layers and suitable for employment with the following currents :—

(*a*)	12 volts . . .	5 amperes
(*b*)	36 ,, . . .	10 ,,
(*c*)	75 ,, . . .	15 ,,

Connecting plugs for putting the layers in series or parallel and for using the layers singly are to be provided, each correctly engraved to indicate its use.

10. *Secondary.*—The secondary is to consist of about 75,000 turns of single silk-covered copper wire wound on a suitable ebonite tube. A suitable wire is about ·008″ thick.

11. *Insulation.*—The insulation from core to primary to be not less than 100 megohms, and from primary to secondary not less than 220,000 megohms, as tested with 500 volts.

12. *Insulating Compound.*—The insulating compound is not to be too brittle at 60° Fahr., and its melting point is not to be less than 130° Fahr.; a sample is to be retained for test by inspecting officer.

13. *Condenser.*—The condenser is to be a variable one well impregnated and having a capacity suitable for the interrupter, so that there is no undue sparking at the contacts. Suitable capacities are 2·25, ·5, ·25, with a total of 3·0 microfarads.

The insulation to be not less than 10 megohms.

Plugs or switch are to be provided for putting different capacities into operation, and these are to be correctly engraved to show capacity of condenser in use.

14. *Commutator.*—The switch is to be of the ordinary reversing commutator type with brass contacts on ebonite or ivory; it is to be placed on the teak base of the coil box, and at as great a distance from the interrupter as possible, in order to avoid the operator receiving shocks.

15. *Inductance.*—The inductance, without iron core, should be about 200 henries, and with iron core about 1,000 henries, with a current of one milliampere.

16. *Efficiency.*—The coil must give a full 10″ spark in air and must not consume more than 10 watts per inch of sparks. The coil is to be entirely suitable for X-ray work in India.

17. *Tests.*—Tests of resistance, insulation, inductance, and capacity will be made.

The coil is also to be run for one hour at ordinary temperatures, and for not less than half an hour at a temperature of 90° Fahr., sufficient time having elapsed to allow of the coil having obtained this temperature throughout. Resistances may be taken before and after these runs.

The coil is also to be run with a spark gap of 6″, one pole being earthed.

X-ray Specification No. 3B.

INDUCTION COIL, BOBBIN TYPE

1. *Coil.*—The coils are to be of bobbin type, of either the "Twelve-inch" or the "Sixteen-inch" variety, and each variety may be required to work on either 220 or 110 volts D.C.

The secondaries of each variety are to be identical for the two voltages, adaptation to voltage being made by the introduction of a suitable primary coil. Suitable condenser and primary coil terminals are to be provided for connection by cable to the interrupter. The primary tube is to be stout and of good quality ebonite or micanite tubing of extremely high insulation capable of withstanding the full voltage of the coil between its inner and outer surfaces. The primary coil is to be capable of being easily withdrawn for repair or replacement. Lacing will not be permitted. The wax used in the construction of the coil is to be suitable for moderately warm climates, and must not melt at a temperature below 130° Fahr., neither must it be brittle at a temperature above 60° Fahr.

2. *Cradle and Condenser.*—Each coil is to be mounted on a suitable cradle, the base of which is to have dimensions 30″ × 16″, and is to contain a condenser of 1·25 microfarad capacity enclosed in a three-ply wood box of the following dimensions:—25″ long × 8⅞″ wide × 1⅝″ thick. The condenser box is to be enclosed in a compartment in the base, from which it can be readily withdrawn endwise for repair or replacement. The brackets mounted upon the base to form the cradle are to be so placed that the coil is supported by its cheeks. The cradles are to be constructed of well-seasoned teak, oak, or mahogany free from large knots.

3. *Discharging Pillars and Points.*—Discharging pillars and points, as detailed below, are to be mounted upon the cradle base by the side of the coil in such positions that a space of 11″ is possible between the sparking points in the case of the "Twelve-inch coil," and 15″ in the case of the "Sixteen-inch coil."

The pillars are to be made of ebonite 1½″ in diameter and are to be fitted at their upper ends with metal discharging points, and with terminals for connecting the latter to the secondary terminals of the coil, the mechanical rectifier of the interrupter, and the overhead wires. One of the discharging pillars is to be fixed in position, the other is to slide in a suitable guide, and is to have affixed to its base a pointer moving over a scale of such a kind as to enable the spark gap to be read in inches at a reasonable distance. To the movable pillar and near its base is to be attached by a double-eye connection, an ebonite handle 1′ long to enable the pillar to be moved while the current is passing. The terminals of the fixed discharging point are to be suitable for ordinary wire connections; those of the movable pillar are to be arranged to take two spring rheophores, one for the horizontal connection to the mechanical rectifier, the other for the vertical connection to the overhead lead.

It is essential that the discharging pillars be sufficiently far from the coil to permit of the mechanical rectifier being connected in circuit between the movable pillar and the corresponding secondary coil terminal.

5. *Interrupter for Tests.*—All coils are to give the output prescribed in the following paragraph when worked in conjunction with a motor-driven interrupter as described in Specification No. 4A.

6. *Tests.*—

(*a*) *Output.*—For testing output a dry tungsten-target tube will be used, of hardness equivalent to a spark gap of 6″, while a current of 10 milliamperes is being passed through it. When a current not exceeding 15 amperes, as measured by a moving coil ammeter, is passing through the primary, the following outputs will be required *:—

Twelve-inch.

On 220 volts D.C. supply, not less than 12 milliamperes
On 110 ,, ,, ,, 8 ,,

Sixteen-inch.

On 220 volts D.C. supply, not less than 16 milliamperes
On 110 ,, ,, ,, 10 ,,

(*b*) *Insulation.*—All coils are to be capable of passing the following insulation tests:—

A discharge will be passed for five minutes between discharging points set at a distance apart 1″ less than the nominal spark gap with any primary current up to 15 amperes at normal speed of interrupter. The rheostat will then be set to give a current of 10 amperes in the primary, after which, without altering the rheostat, the speed of the interrupter will be varied between very wide limits, the action of the coil being finally stopped by gradually reducing the speed of the interrupter to rest. At the end of the above test the coil will be required to give the output specified under (*a*).

A temperature test may be required immediately before or after the above test and will be as follows:—Coils are to be able to withstand a run at normal output in a temperature of 100° Fahr. for half an hour after sufficient time has elapsed for the heat to penetrate to the inner windings.

The insulation between various parts when measured with a 500-volt "megger," immediately after either or both of the above tests, is not to be less than—

(*a*) Between primary and secondary .	100 megohms.
(*b*) Between primary and core . .	20 ,,
(*c*) Condenser	10 ,,

The coils are further to be capable after any or all of the above tests of withstanding a run for one minute with a current of 10

* This used formerly to read:—16″ coils worked from a 200-volt direct current supply must be capable of sending through a non-inductive water resistance equivalent to a spark gap of 5″ in air at normal temperature and pressure, a current of not less than 18 milliamperes, with a current not exceeding 10 amperes passing through the primary as measured on a moving coil ammeter, 12″ coils worked from a 100-volt direct current supply must be capable of giving 9 milliamperes under similar conditions.

amperes passing through the primary while one end of the secondary is earthed through a 6″ spark gap.

7. *Diagram of Connections.*—On each coil is to be affixed in a prominent position a varnished diagram of connections of the coil, condenser and interrupter, with plainly indicated references.

INTER-DEPARTMENTAL ADVISORY COMMITTEE ON X-RAY AND ELECTRO-MEDICAL APPARATUS.
September, 1919.

X-RAY SPECIFICATION NO. 4A.

MOTOR-DRIVEN INTERRUPTER.

1. *General Description.*—The interrupter is to be of the mercury jet type, motor-driven with vertical spindle arranged to carry a mechanical rectifier, and is to be designed to work alternatively on a 200–220 volt or on a 100–110 volt direct current supply by fitting appropriate contact blades as explained below. The container is to be a metal casting provided internally with projections to prevent the rotation of the mercury as a whole. The mercury pump and container are to be constructed in such a way that not more than 8 lbs. of mercury are required for satisfactory working. Either of the following types of interrupter may be supplied:—

(*a*) The type in which the motor is mounted on a bracket alongside the container driving the interrupter by means of a belt running on pulleys of equal size.

(*b*) The type in which the motor is mounted over the container driving the interrupter direct.

2. *Interrupter Blades.*—

(*a*) For 200–220 volts four contact blades are to be fitted, the horizontal length of each of which is to be equal to the radial distance to the blade surface from the central axis of rotation of the interrupter.

(*b*) For 100–110 volts two blades are to be fitted, the horizontal length of each of which is to be twice the radial distance of the blade surface from the central axis of rotation of the interrupter.

As the interrupters may be required to be used either on 100 or 200 volts they are to be so constructed that the change from one set of blades to the other may be easily carried out.

The radius of the contact blades is not to be less than 6 cms. and not greater than 8 cms., and the blades are to be well amalgamated with mercury.

3. *Dielectric.*—The interrupter is to be arranged for the use of coal-gas or the vapour of a volatile liquid as dielectric. The container must be made gas-tight, being fitted with a lid fastened by studs and nuts No. O.B.A. to a flange on the vessel, the joint being packed with a flat rubber washer. The studs are to carry immediately beneath the nuts stiff spring washers, the threads of the studs being terminated in such a manner as to prevent the spring washers from being screwed down to less than $\frac{1}{8}''$ of absolute tightness. The object of this arrangement is the provision of a safety valve in the event of an accidental explosion in the interrupter.

4. *Motor.*—The driving motor is to be one of two standard types according as:—

(*a*) It is mounted on a bracket alongside the container.

(*b*) It is mounted above the container.

In both cases the motors are to be well insulated from the live circuits of the interrupter. The motors when required for use with standard switchboards are to be 100–110 volt machines whether operating from a 100–110 volt circuit or a 200–220 volt circuit. Provision is made in the latter case for applying only the lower voltages by a suitable series resistance in the motor circuit of the switchboard. The motors will run at a normal speed of 1,500 R.P.M., but will be capable of regulation by the switchboard rheostat to speeds down to 1,000 R.P.M. When required for use with switchboards specially designed to work on 200–220 volts, motors for this range of voltage are to be provided.

CHAPTER XII.

INSULATING MATERIAL.

Insulating materials may be divided for convenience into three classes, solid, semi-solid, and liquid, the first being the most important. It is not proposed to treat with all insulating substances, but only those that come more particularly within the scope of coil building.

Ebonite.

Ebonite, or sulphuretted caoutchouc (sometimes loosely called vulcanite), one of the most important insulators in coil construction, consists of hard vulcanised india-rubber, that is, pure rubber mixed with from 20 to 30 per cent. sulphur and loaded with other ingredients to give the necessary body and colour, after which the rubber is vulcanised or cured in steam-heated ovens for a prolonged period.

The best ebonite is nearly pure vulcanised rubber, but inferior ebonites are generally made from recovered rubber or other undesirable substances, sometimes including even metal filings.

An Admiralty specification gives the proportions of $33\frac{1}{3}$ per cent. clean washed sulphur to $66\frac{2}{3}$ per cent. pure Para rubber.

The best quality ebonite is hard and tough and should cut fairly, but not too easily, with a penknife.

If ebonite is brittle it is over-vulcanised and should not be used; if putty like, with a strong smell of linseed oil, it is under-vulcanised and should either be rejected or returned for a further period of vulcanisation.

Ebonite tubes for electrical purposes are made by wrapping several turns of the sheet rubber dough round a metal mandrel of the required size. The rubber has to be tightly wrapped to exclude air bubbles and moisture, and is then finished by binding with canvas, after which it is vulcanised. In order to withdraw the mandrel this is generally slightly tapered, and tubes should be examined for this before work is begun. Sheet ebonite is prepared in a similar way, but in order to obtain a fine surface the dough is generally placed between sheets of tin-foil before being placed in the press which, in most cases, is itself steam-heated and forms the vulcanising oven. Ebonite is usually of a brilliant black colour, but the mottled black and brown variety is, in the writer's opinion, equally good if not better from an insulation point of view. As ebonite ages, particularly if exposed to bright sunlight, a greenish covering forms on the surface which is not only unpleasant in appearance but also considerably lowers its insulating properties. This greenish appearance may be partly eliminated by treating the surface of the ebonite with a paste of magnesium carbonate, which should be allowed to remain some hours before being wiped off. If the highest finish is not required a protective varnish, consisting of a mixture of black spirit varnish and shellac varnish, may be applied with a wide camel-hair brush.

This does not lower the insulating properties of the ebonite and preserves it from ageing, and damp, as above described.

For the finest finish the ebonite parts should be treated with fine emery or glass paper, finishing up

with French "blue back" emery paper, after which bath brick and oil should be applied on a cotton pad and finally a buff should be used treated with rotten-stone and oil. Finally, the work may be polished with a soft rag and paraffin oil. During these processes the ebonite should not be pressed too tightly or otherwise it will get warm, in which case a fine finish is impossible. In machining ebonite, brass tools, such as taps, counter-sinks, etc., are often preferable to steel, as, owing to the nature of ebonite, steel tools are very quickly blunted.

Ebonite may be readily bent or moulded by applying gentle warmth either by hot water or working on a hot plate, and this property is often useful in making experimental primary tubes, curved discharger pillars, etc.

Fibre.

Fibre, sometimes incorrectly called "vulcanised" fibre, which should not be confused with ebonite, consists of wood fibre treated with acids, washed, and compressed under hydraulic pressure, when it becomes a tough, horny product of great strength but of poor insulating qualities. It should never be used for high tension work as a substitute for ebonite, as it leaks badly, being very hygroscopic. It can be used for moderately high pressures if boiled in paraffin wax, but is chiefly useful for low tension work, *e.g.* cheap switch handles and bushes. Fibre is made in two kinds: hard, in rod and sheet for machining, and soft, like leather, for low tension insulating purposes, *e.g.* for placing between primary layers. Either variety, if used, should be heavily varnished to exclude moisture as far as possible.

Paper and Cardboard.

Paper consists of vegetable fibres, practically cellulose, felted or matted together so as to form one sheet. The material from which these fibres are taken may be linen, or cotton rags, straw, wood, esparto grass, flax, hemp, jute, etc. The material is first cleaned, then boiled in alkali, usually under pressure, after which it is bleached. Finally the pulp is beaten up in an engine adapted to give the fragments the maximum of felting power, and various loading, sizing and colouring agents are now added.

The pulp is finally made into paper by catching the fibres of the pulp diluted in water on a frame of wire cloth called a deckel. The frame is hand-operated, and paper so made is called hand-made paper. Such paper, though expensive, is used for bank-notes, drawing paper, etc., on account of its strength. In machine-made paper the frame is replaced by an endless band of wire cloth on which the pulp flows leaving the other end of the machine as a continuous roll of paper. Machine-made paper is generally weaker transversely than longitudinally. Reference has been made to loading, sizing, and colouring agents. The loading agents used are usually china clay, steatite, calcium sulphate, starch, etc., and are harmless from an electrical point of view; this also applies to sizing, which usually consists of resin size (resinate of alumina), and gelatine and alum in the case of hand-made paper, but it is better to use unloaded and unsized paper if possible. Coloured papers should not be used, although an apparently white paper may have been actually coloured, by the addition of pink or blue in order to correct an initial yellow tinge.

It is difficult to give any guide for judging the electrical qualities of paper, each specimen must be

tested separately, but widely speaking, an examination under the microscope will help considerably, as too will the taste and feel of the paper in the mouth when moistened, examination of the paper during and after boiling in a glass beaker, its mechanical strength lengthways and widthways, and when folded, the appearance of the paper and its flame as it burns and the appearance and weight of the ash after incineration, are all good guides after some practice.

The following are some of the more common papers used for electrical purposes.

Manilla Paper, a tough, coarse, yellowish paper made from Manilla or wood pulp. Chiefly useful for constructing primary tubes of small coils, also for general purposes when impregnated, or for oil-immersed coils and transformers.

Blotting Paper is generally made from cotton rag pulp very lightly sized with starch. A useful paper on account of its capacity for absorbing paraffin wax, etc.

Demy Paper, a soft paper of cream colour, having a regular mottled surface, made from Esparto. Very useful for condensers and particularly for insulating the secondary in layer winding or forming the separating discs in section wound coils. Readily absorbs wax and is a good insulator. Usual thicknesses from 1·5 to 2·5 mils.

Parchment Paper consists of strong unsized paper dipped for a few seconds in diluted sulphuric acid, after which it is washed in an alkaline solution.

Bank-note Paper, a thin, tough, semi-transparent paper made from linen fibre, generally by hand. An excellent insulation for secondaries or condensers, but expensive.

There does not appear to be much difference in the insulating properties of any specimen of paper when

used alone. The function of the paper seems to be to a great extent to act as a vehicle for absorbing a quantity of the insulating material. This is true, however, only to a certain extent, as blotting paper, though a good insulator when waxed, is surpassed by other mechanically harder and tougher papers. Generally speaking, it is preferable to use two papers of half thickness to one single paper, as by this means not only is a film of insulating material sandwiched between the papers, but the likelihood of two faults in the sheets becoming superimposed is rendered very remote.

Paper in its usual state contains a large quantity of moisture and it cannot be too strongly recommended that all paper used for highly insulating purposes must be thoroughly dried in an oven or by other suitable means before being boiled or impregnated with wax.

The difference between two similar pieces of paper, one dried and the other undried, may amount to a spark-resisting property of over 100 per cent. in favour of the dried specimen.

Care should be taken, however, not to overheat or char the paper when drying.

Paper chars at about 350° F., but there is no need usually to raise the temperature to anywhere near this limit, 250° F. is ample to expel all moisture.

Cardboard.

Cardboard is made in two varieties, pasteboard and strawboard. Pasteboard, as its name implies, consists of several sheets of paper pasted together and then rolled or pressed into intimate contact. Strawboard consists of a homogeneous, spongy, fibrous material rolled out in one piece to the required thickness. Although strawboard is capable of absorbing large quantities of wax or other insulation it forms a very

poor insulator and should not be used for any but the lowest pressures. Pasteboard, on the other hand, is an excellent insulator, particularly if the sheets are stuck with paste and not with glue, as paste absorbs wax while glue does not. A good substitute for flour paste is gum tragacanth. Moulded insulators can easily be made from pasteboard or paper pasted together and then boiled in wax. For small coils, primary tubes and the like, also the washer separators for sections, can be made suitable in this manner.

Paxolin (Admiralty quality) is a tough, brown material of excellent insulating properties especially across the grain, composed of compressed paper cemented together with paxolin varnish, that is a mixture containing, for the most part, phenol acted on by formaldehyde. Paxolin can be readily machined and, unlike ebonite, stands a considerable degree of heat and ill-usage without injury. Although not such a good insulator as micanite or ebonite, it can be used with advantage for coil decks, cheeks, etc., if strength rather than a high degree of finish is the chief object.

Varnished Paper and Cloth.

Varnished paper, cloth, or silk form excellent insulators where no very high pressures are likely to occur. Varnished paper can be used for insulating the core from the primary in small coils and for the manufacture of condensers. For larger coils varnished cloth or silk should be used for wrapping cores and primary windings.

The varnish applied to the cloth or paper consists chiefly of linseed oil with various drying agents. A good paper or cloth should feel tacky to the touch without actually sticking, and when handled should be quite limp without any tendency to form creases which materially lower the resisting power of the material.

When viewed with a good light behind, the paper or silk should present a homogeneous appearance devoid of irregularities or foreign matter.

The Micanite & Insulators Co. give the breakdown voltage per mil for their varnished cloth as 900 to 1,400 volts before baking, and 1,090 to 1,470 volts after baking, and for paper 1,000 to 1,700 volts.

Generally speaking, 1,000 volts per mil is a good working rule provided the cloth or paper is not creased, in which event its resistance may fall quite 75 per cent. Stoveing varnished papers and cloth should be avoided, if possible, or only be carried out at low temperatures. In varnishing coils insulated with varnished cloth or paper special varnish obtained from the makers should be used, not shellac or asphaltic varnishes, nor wax, resin, or the like.

Breakdown Voltages.

Mils. Thickness.	Cloth. Volts.	Paper. Volts.	Presspahn. Volts.	Silk. Volts.
1·5	—	2 000	—	—
2·5	—	3 000	—	—
3	3 000	4 000	—	—
4	4 000	5 000	—	4 500
5	5 000	6 000	5 000	—
6	6 000	7 000	—	6 000
7	7 000	—	—	—
8	8 000	8 500	6 000	—
9	—	10 000	—	10 000
10	9/10 000	—	6/10 000	—
12	10/11 000		—	
14	12 000		6/10 000	
15	12 500		10 000	
18	—		10 000	

Glass and Porcelain.

These do not enter into the construction of coils to any great extent, although both have been used to

form the insulating tube between the primary and the secondary, glazed and porcelain tubes are still so used. Glass is chiefly employed in the manufacture of condensers, Leyden jars or the like, and should for this purpose be of the best flint glass. Glass, unless oil-immersed, is very subject to surface leakage and care must be exercised in this respect. On this account the exposed surfaces of glass are either heavily shellac-varnished or else coated with paraffin.

Mica and Micanite.

Mica is a natural mineral, chiefly composed of silica and imported mainly from India and Canada, possessing the characteristics of splitting easily into thin laminæ, transparent and flexible. It is a good insulator and of high specific inductive capacity. The best quality is known as clear ruby mica and should be free from spots or flaws due to ferrous oxide which greatly reduce its insulating qualities.

Owing to its high cost in large sheets small pieces of mica are cemented together to form micanite. Micanite can be made not only in sheets but in tubes and other moulded forms, as the cement used consists chiefly of shellac, which softens with gentle heat, enabling the desired form to be shaped out.

Where higher temperatures and pressures are used micanite is cemented with a compound containing paxolin (formaldehyde) varnish.

The dielectric strength of micanite sheet is given as 1,012 volts per mil, but a sheet $\frac{1}{4}''$ thick will withstand a 16″ spark for some minutes and can be relied upon for a 12″ spark indefinitely when used as the primary tube of a coil. Micanite also forms an excellent dielectric for condensers, *q.v.* Mica and micanite have a tendency to great surface leakage and become very highly electrified. It is therefore

desirable to leave a large surface as a margin of safety or the spark will leap over the previously electrified surfaces. To prevent this micanite primary tubes should be covered by a thin ebonite tube cemented on.

Paraffin Wax.

Paraffin wax, which is one of the most useful and widely used insulators for coil manufacture, is extracted from shale oil or petroleum. In some processes sulphuric acid is used in the treatment, hence when using paraffin wax precautions must be taken to neutralise any free acid remaining. Paraffin wax should be white and show a well-crystallised fracture, its melting point, which varies between 100 and 140° F., should be tested, and only the best permissible wax should be used for first-class coil and condenser work, the hardest quality wax being known as Galician wax. Paraffin wax contracts strongly on cooling and when casting up large masses precautions must be taken to counteract the shrinkage before it finally sets. Paraffin should not be unduly heated as it loses its properties if a temperature much in excess of 212° F. is exceeded. As, however, paraffin contains a certain percentage of moisture it is advisable to heat it for a short period to a temperature not exceeding 250° F. This tends to drive off, in the form of steam, the occluded moisture not only in the wax but in the material under treatment. A moderate heat should subsequently be applied to the bath as long as bubbles continue to rise from the material under impregnation.

It is wise to allow the bath to set completely and then to reheat for a short period before finally allowing the bath to set. This will eliminate all air bubbles and moisture as far as is possible without using a vacuum tank.

When preparing the paraffin bath it is advisable to sprinkle in a handful of freshly-heated powdered chalk,

which will eventually fall to the bottom of the tank. The chalk should be allowed to remain there in order to neutralise any free acid remaining in the wax which would tend to attack the secondary windings or tin-foil under treatment. A thermometer should be kept permanently in the bath and carefully watched, particularly if it is not water-jacketed or steam-heated. With continued use the wax will, sooner or later, turn yellowish and a fresh bath should be made up keeping the old material for casting up, filling in coils and the like, when its insulating properties are not of the first importance.

Beeswax.

Beeswax is obtained from honeycomb, being, in the first place, a secretion from the body of the honey bee. Commercial beeswax can be obtained fairly pure, but if doubts are entertained it is best to boil the wax in a pan of hot water, when the dead bees or brood can be skimmed off; the pollen and propolis with any dirt either falling to the bottom of the pan or forming a coating to the underside of the cake of wax when it sets, where it can readily be scraped off. Besides containing mechanical foreign matter beeswax is often adulterated with paraffin wax, fat, resin and the like, and can only be judged by experience. Good wax is dark yellow in colour and has a strong, pleasant, honey-like smell; on fracture it shows a granular grain. Its melting point is from 144 to 150° F. It contracts on cooling, but not so much as paraffin wax; on the other hand, unlike paraffin, it is very liable to contract in fissures and on this account it is usually used mixed with resin. White or light-coloured wax should not be used, as to obtain this colour, which is not natural, the wax is bleached with chlorine, thereby denaturing it and making it more brittle.

With regard to heating and treatment the remarks on paraffin apply to beeswax also.

Resin.

Resin is an exudation from the stems of trees. Ordinary resin, or colophony, is the residue remaining after the turpentine with which it is associated has been distilled off. Sources of resin are chiefly French and American, the latter being darker in colour. The melting point is from 212° to 275° F., but it becomes soft about 180° F.

When melted the resin will probably be found to be mixed with a quantity of mechanical impurities, stones, wood, etc., but these, as well as the scum which rises when first the resin is melted, can be removed with a perforated ladle or strainer. Resin is a very good insulator, but has the disadvantage that it becomes very brittle at low temperatures. For this reason it is usually mixed with beeswax in quantities varying from the proportion of equal parts by weight to one part of beeswax to three parts by weight of resin, and such mixtures give excellent results. With the higher proportion of beeswax it is unnecessary to add tallow as is sometimes advised, besides which tallow is a poor insulator and a little too much would reduce the melting point to an undesirable degree, as it does not seem possible to assume the mean of the melting points of two or more waxes, the resulting melting point being nearly always in the neighbourhood of the lowest ingredient present, provided, of course, that the proportions of the waxes bear some relation in weight to one another.

Shellac.

Shellac is a resin chiefly used in the manufacture of shellac varnish, although raw shellac flakes are useful

for cementing parts of electrical apparatus where a good insulator is required. Shellac varnish is prepared by slowly dissolving about 4 ozs. of shellac in 1 pint of methylated spirit. Naphtha is sometimes substituted for the spirit. Generally speaking, shellac varnish should not be used for varnishing primaries and similar windings as it has a tendency to rot the cotton coverings, especially if the coil be overheated. It is, however, a very useful varnish for applying to surfaces of glass or ebonite exposed to the air or moisture where higher pressures exist with a tendency to brushing or sparking over. For treating ebonite a little vegetable black can be added, or better, use a half-and-half mixture of shellac varnish and Club Black applied quickly with a broad camel-hair brush. As shellac is not appreciably attacked by oil, it is useful for painting the interior of wooden cases used to contain oil-immersed coils. Four or five coats of thick varnish should be used.

Miscellaneous.

Vaseline, or petroleum jelly, is sometimes used as a semi-solid insulator for coils and transformers. The vaseline is first heated and then poured into the receptacle containing the coil.

Paraffin Paste is another semi-solid insulator prepared by dissolving various proportions of paraffin wax in paraffin oil, 12 to 14 ozs. of wax in 1 pint of oil form a serviceable mixture. Semi-solid insulators are useful for immersing Tesla or high-frequency coils where portability is desired, as they are not open to the objections of slopping and spilling of mineral oils.

Resin Oil and Linseed Oil are used for oil-immersed coils, both ordinary and high-frequency, and transformers. They are good insulators, but liable to dry on the surface and form nodules of condensed gummy

matter after a time on the walls of the tank and the coil windings themselves.

Paraffin Oil has none of the disadvantages of the two preceding oils and is an even better insulator, $\frac{1}{4}''$ of oil withstanding a $1\frac{1}{2}''$ to $3''$ spark in air, depending on the degree of sharpness of the needle points of the alternative gap. It is cheap and clean to use, but has the disadvantage of creeping. The container, particularly if of wood, should therefore be made deeper than is actually necessary, to avoid loss by capillary attraction.

An insulating wax for a well-known coil of Continental manufacture is composed as follows :—

Resin	15·0	parts
Paraffin wax	7·0	,,
Beeswax	2·4	,,

and Moscicki wax—

Resin	4	parts
Ozokerite	1	,,
Vaseline	1	,,

A red cement wax for filling in coils—

Resin	16	parts
Paraffin wax or beeswax	4	,,
Whitening	16	,,
Red ochre	4	,,

The following values from an American source are given for what they are worth :—

Rupturing E.M.F. in Kilovolts per Inch.

Ebonite	900–1 500
Glass	500
Glass, window	380–1 000
Guttapercha	250–1 000
Mica	1 500–5 000
Micanite	2 500–7 500
Paraffin wax	330–650
Petroleum	230

CHAPTER XIII.

INDUCTION COIL DESIGN.

THE design of induction coils is an exceedingly complex problem, and while coil design must always remain to a considerable extent a matter of experience, yet a certain amount of calculation can with advantage be applied to the subject.

The work for which a coil is intended has a great influence in determining the actual windings, size of coil, etc., which are to be employed.

Thus, a coil designed for Röntgen Ray work may differ considerably in these particulars from one intended for charging condensers for wireless transmission.

We will now endeavour broadly to apply those principles and data which have been indicated in the preceding pages.

In most cases the data available when beginning design of a coil are—

1. The spark length in inches, and
2. The secondary current in milliamperes as determined by a hot wire ammeter.

From the spark length in inches the sparking voltage can be obtained by reference to the curve (maximum of sparking distance) in Fig. 66, Plate I.

By multiplying together the secondary voltage and

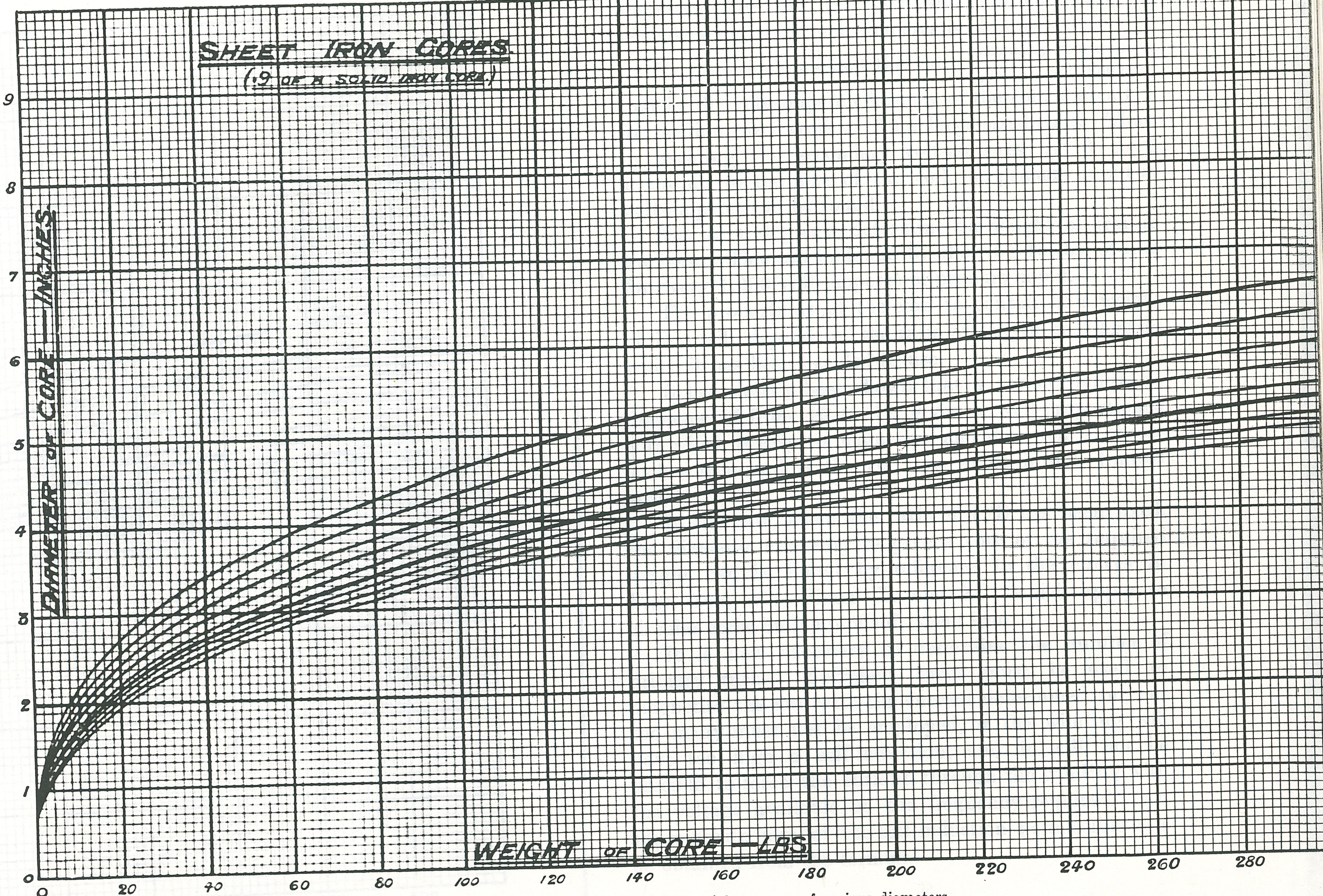
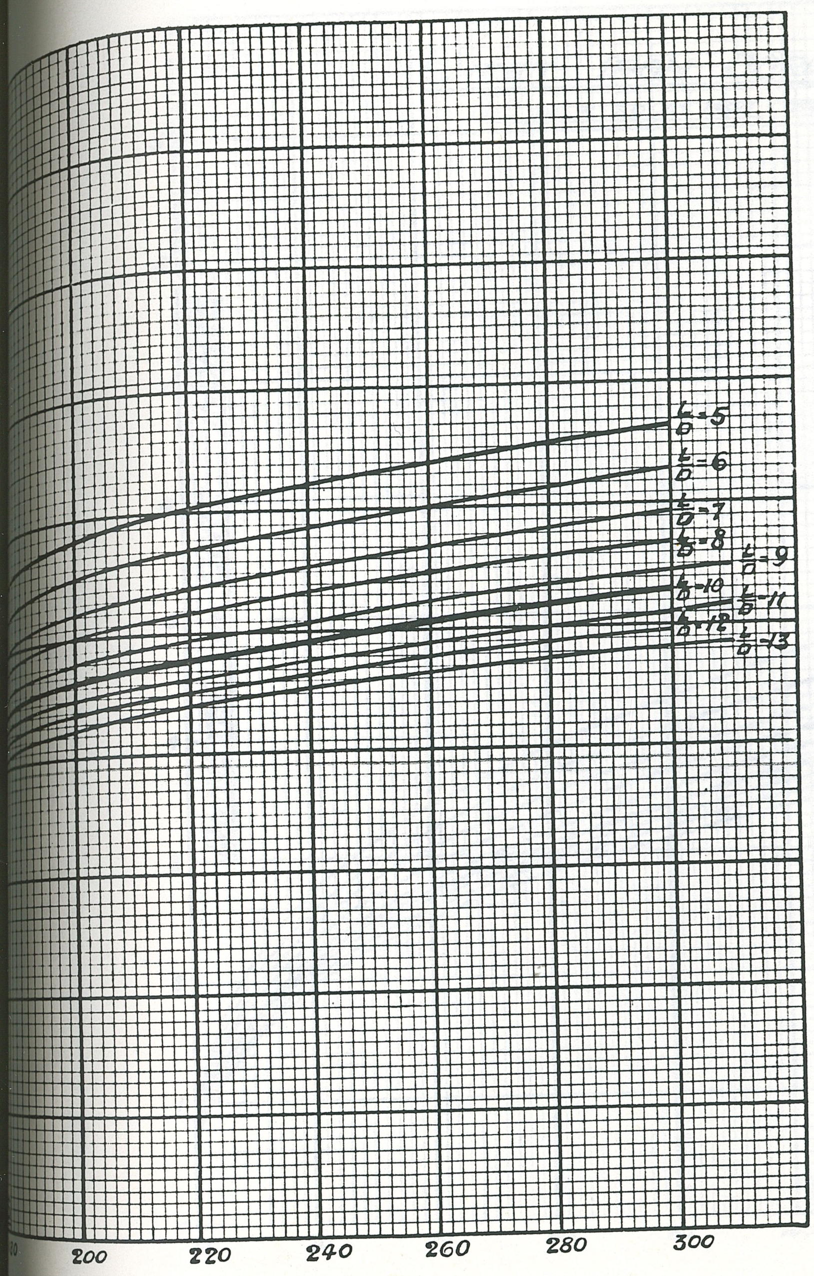


FIG. 164.—Table of weights of iron cores of various diameters.

PLATE. XI.



various diameters.

[E. & F. N. Spon, Ltd.

ampereage (or the kilovolts and milliamperes) the secondary output in volt-amperes is obtained.

Experience shows that the ratio $\frac{\text{secondary volt-amperes}}{\text{primary volt-amperes}}$ that is, the volt-ampere efficiency of the coil, is about ·3 for medium-sized coils to ·6 for large-sized coils. Thus, by dividing the secondary volt-amperes by ·3 to ·6 according to the size of the coil, the primary input in volt-amperes can be found.

The next step is to determine the weight of iron in the core. This can be found by allowing 15 lbs. of iron for every 1,000 volt-amperes of primary input.

The proportions of the core to contain this weight of iron will depend on the ratio of length to diameter which it has been decided to use.

It has already been shown that a ratio of length to diameter of from 10 to 12 gives a well-proportioned core which is easy to magnetise, and it is well to choose such a ratio unless the coil has to fit into a limited space.

In any case, when the ratio of L/D has been fixed, the diameter necessary to give a core of the required weight can be found by reference to the curves in Figs. 163, 164, Plates X. and XI., which apply to circular cores built up of soft sheet iron.

It is now necessary to determine the number of primary turns. Sufficient turns must be used to magnetise the core with the current determined on, but too many must not be employed, or the winding will have too high a self-induction, and it will not be possible to force the current through the winding with the voltage available at the frequency required. An approximate idea of the self-induction permissible can be obtained from the formula—

$$L_p = \frac{E}{\pi f C}$$

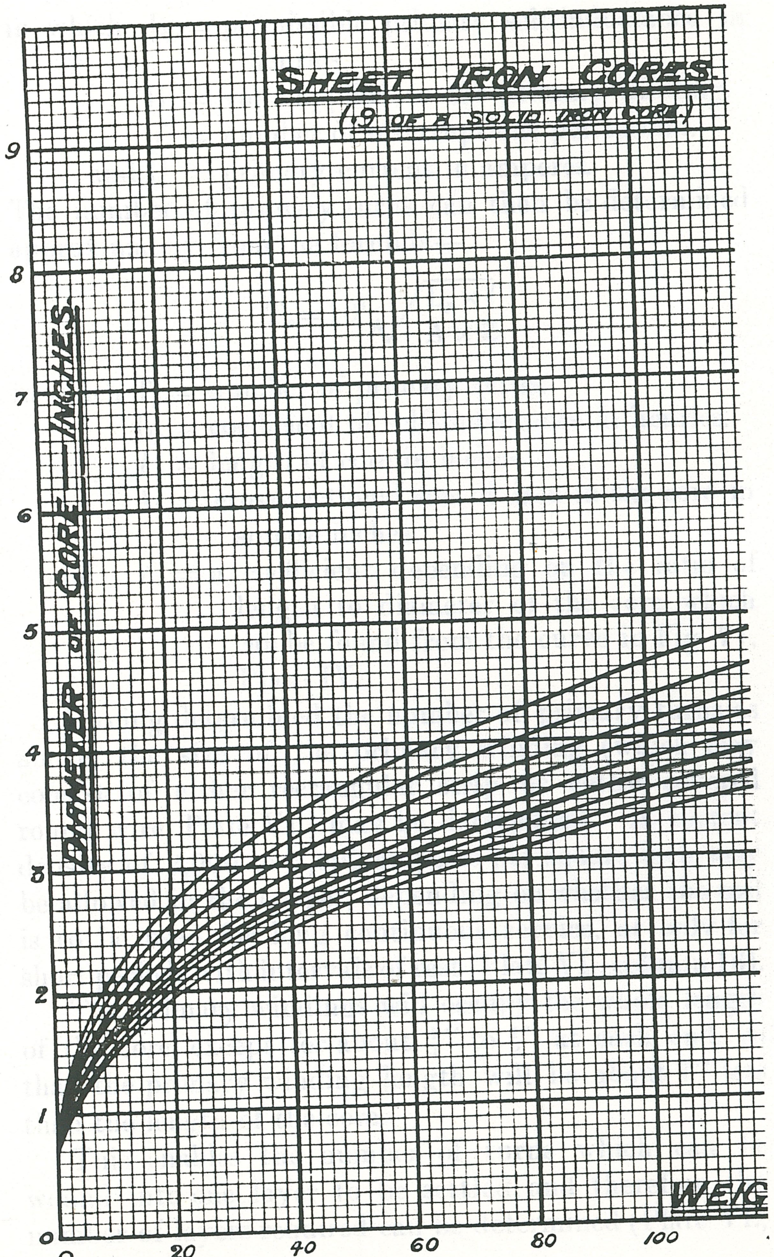


FIG. 1

To face p. 229. Codd, "Induction Coil Design."]

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$$L_p = \frac{E}{\pi f C}$$

in which L_p = permissible primary self-inductance in henries.

E = volts applied to the primary winding.

f = number of interruptions per second.

and C = primary current in amperes.

The number of primary turns can then be determined approximately from the formula—

$$T_p = 10^4 \sqrt{\frac{L_p \times l}{A \times Z}}$$

in which T_p = number of primary turns.

L_p = coefficient of self-inductance in henries.

l = length of core in inches.

A = cross-sectional area of iron in the core in square inches.

and Z = a coefficient depending on the ratio of length to diameter of the core which can be found from the curve in Fig. 71, Plate IV.

Having determined the number of primary turns as above, the size of the primary winding (which may consist of either rectangular strip or cotton-covered round wire, Plate VI.) may be determined. A current density of 2,000 to 3,000 amperes per square inch may be allowed in the copper, depending on whether the coil is to be used for long continuous service, or only for short periods with intervals of rest (Plate VI., column 16).

The primary windings will occupy the whole length of the core, except for about $\frac{1}{4}''$ to $\frac{1}{2}''$ at each end, so that the primary winding length will be about 1″ less than the length of the core.

This enables the number of turns which can be wound into one layer to be settled, and therefore the number of layers required can be determined (Plate VI., column 10).

From the number of layers and the size of the

conductor the depth of the primary winding is at once found, and allowing for a sufficiency of insulating tape between the layers, the internal diameter of the primary insulating tube can be fixed.

The thickness of the tube is a matter for experience, and depends on the duty the coil is required to fulfil, but ·25″ of micanite or the very best ebonite, will be sufficient insulation per 12″ of spark length, provided the coil is not earthed at one end at full pressure. The length of the tube can be arrived at by allowing an average length of twice the spark length in inches, greater or less according to the method of insulation employed.

We now come to the secondary winding. As has been explained on p. 62, the distance between the true magnetic poles of the core is less than the total core length by about one diameter; also it is not economical for the secondary to occupy more than 80 per cent. of the distance between the true magnetic poles.

The maximum secondary winding length is thus $\cdot 8(l - d)$, where l is the length of the core and d its diameter, both in inches. Also the secondary must not be smaller in length than 1·33 times the spark length required.

If these two desiderata cannot be reconciled, it is necessary to redesign the coil with a different ratio of l to d to enable this to be done.

Assuming that the secondary winding length has been satisfactorily determined, the number of secondary turns can be approximately arrived at, (a) by allowing a transformation ratio of primary to secondary turns of from 75 to 1 for a large coil to 150 to 1 for a small coil, and (b) by allowing 5,000 turns per inch spark length desired, when working at a saturation of from 60,000 to 80,000 lines per square inch, in coils of

medium size, thus for smaller coils, having a less total flux, more than 5,000 turns per inch will be required, and *vice versâ*.

It should be noticed that the transformation ratio forms a valuable guide to the primary voltage which the insulation of the primary has to withstand. For example, in the coil under consideration, if the number of secondary turns (60,000) to the number of primary turns (600) have a transformation ratio of 100 to 1, and the maximum secondary sparking voltage is, say, 175,000 volts the maximum primary voltage will be 1,750 volts over the windings, and sufficient insulation must be placed between the layers to prevent this voltage jumping from layer to layer, thereby causing a short and burning out the primary. The necessary gauge of secondary wire can be determined from Plate VI., column 16, but for most medium coils No. 36 is a suitable gauge and No. 34 or 32 gauge for large wireless or single-flash coils.

The differences which may occur between (*a*) and (*b*) must be reconciled by reference to the work to which the coil is to be put, as will be subsequently explained.

Example.—Let us now take as an example a medium-sized coil capable of giving a maximum spark length of 12″ and a secondary current of 5 milliamperes.

$$\begin{aligned} 12 \text{ inches} &= 175{,}000 \text{ volts} \times \cdot 005 \text{ ampere} \\ &= 8{,}750 \text{ volt-amperes} \end{aligned}$$

Taking the efficiency at ·4 the input will be 2·187 KVA. Presuming that the pressure on which the coil is to work will be 220 volts, this will give a maximum working current of approximately 10 amperes.

Taking the input at roughly 2·2 KVA. the weight of iron required will be 33 lbs. and using a ratio of L.D of 10 from the curve in Fig. 163, we see that the

diameter of the core is approximately $2\frac{1}{2}$, therefore the length of the core will be 25″.

From the formula $L_p = \dfrac{E}{\pi f c}$ we have $E = 220$, $c = 10$, and we propose a frequency of 50 interruptions, therefore $L_p = \dfrac{220}{\pi \times 50 \times 10} = \cdot 14$ henry, and from the formula—

$$T_p = 10^4 \sqrt{\frac{L_p \times l}{A \times Z}}$$

$$L_p = \cdot 14$$

$$l = 25 \text{ inches}$$

$$A = 4 \cdot 41 \text{ sq. inches } \left(2 \cdot 5^2 \times \frac{\pi}{4} \times \cdot 9\right)$$

$$Z = 210 \text{ (from curve, Fig. 71)}$$

therefore we have—

$$\begin{aligned} T_p &= 10^4 \sqrt{\frac{\cdot 14 \times 25}{4 \cdot 41 \times 210}} = 10^4 \sqrt{\frac{3 \cdot 5}{926 \cdot 1}} = 10^4 \sqrt{\cdot 00378} \\ &= 10^4 \times \cdot 0615 = 615 \text{ turns} \end{aligned}$$

Referring to Plate VI., column 16, we find No. 14 will carry over 10 amperes at a current density of 2,000 amperes per square inch, which will be sufficient for our purpose, and from column 10 (double cotton-covered), we see that we can wind 10·6 turns per inch run; as there are 615 turns the winding length is $\dfrac{615}{10 \cdot 6} = 57 \cdot 1''$ allowing 10 per cent. for slack winding, this gives a total winding length of 62·8″. The winding space on the core will not much exceed 24″, which gives 2·6 layers, therefore a slightly larger wire may be chosen or three layers of 14 gauge wound on. As will be explained later it is preferable to have half to one layer in excess of that given by the formula, and therefore three layers of No. 14 had best be decided on, giving a total number of turns of about 680.

As there are three layers of wire ·094 thick, the depth of winding on each diameter of the core will be ·282, and, allowing for a sufficiency of insulating tape between the layers, say, $\frac{3}{8}''$. The core being $2\frac{1}{2}''$ diameter this will make the diameter of the primary $3\frac{1}{4}''$, which determines the bore of the insulating tube. As the coil is to give 12″ spark length the walls of the tube should not be less than $\frac{1}{4}''$ thick, if of micanite, and certainly not less, but preferably rather more, if of the best ebonite. This makes the tube $3\frac{3}{4}''$ to 4″ exterior diameter. As the core is 25″ long the tube may for convenience be this length, since twice the spark length is only 24″. Hence the tube will be 25″ long, $3\frac{1}{4}''$ bore, and $3\frac{3}{4}''$ outside diameter.

As the length of the core is 25″ and its diameter $2\frac{1}{2}''$, the length of the secondary winding space $= \cdot 8(l-d) = \cdot 8 \times 22\cdot 5 = 18''$.

Taking a medium transformation ratio as 100 to 1 for a coil of this size, we obtain the secondary turns as $615 \times 100 = 61{,}500$ (a). Estimating 5,000 turns per inch of spark length (b) we get 60,000 turns, which is not incompatible with (a). Since the secondary is to carry 5 m.a., No. 36 will be ample (Plate VI., col. 16) and though a smaller gauge can be used if desired it must be remembered that for smaller gaps the secondary current will many times exceed 5 m.a.

This brings us to the point at which it is necessary to explain several apparently anomalous points which have arisen in this section in design.

Firstly, the coil was taken as giving an output of 5 m.a. at 175,000 volts.

Now, although under certain conditions such a state of affairs may take place, those conditions are usually unstable. Consider first a 12″ gap in air. As is shown by the table of voltages necessary to break down this distance in air, 175,000 volts will be needed, but the

instant that the wall of air between the dischargers is pierced, a conducting tube of hot air is formed and an arc results, the pressure to maintain which will be only of the order of 20,000 volts. As the closure of the secondary circuit is of such comparatively low resistance, there is consequently a much larger milli-ampereage circulating in the secondary, and therefore the primary current will also rise, with a danger of blowing the fuses in the main circuit.

It is on this account that an extra layer of primary winding is an advantage, at any rate till the exact stabilisation of the secondary to primary load has been determined, after which it may be cut out and, circumstances permitting, one layer less may be used.

With a cathode tube the same state of affairs obtains in a rather lesser degree.

Assuming a fairly hard tube to be used, 175,000 volts may be necessary to break down its initial resistance when cold, but once the tube is working its resistance falls till a pressure of about 50,000 volts is sufficient to maintain it in action.

The result is that a much larger current than 5 milliamperes flows, perhaps 15 to 20, hence a proportionally larger primary current will be drawn from the mains.

The tube, however, may be a very soft one, in which case the primary current will be very high, and under these conditions the extra layer of primary winding may be economically used.

Conversely, if the tube is exceptionally hard, a higher voltage must be maintained, in which case a layer of primary winding can with advantage be cut out in order to pass sufficient primary current to energise the core.

In other words, a variable transformation ratio is desirable, low for soft tubes or a short arcing gap, and

high for hard tubes, or where a full tension is desired over long distances, where the spark cannot turn into an arc (*e.g.* ozone production).

The method of winding the secondary may be any of those described in Chapter VI., which commends itself to the operator, bearing in mind the necessity of good insulation. The outside diameter of the secondary should not at most exceed 2·5 times the bore for the best effect, and since this is $3\frac{3}{4}''$, the maximum diameter will not be more than $9\frac{1}{8}''$. Generally speaking, the depth of secondary winding does not much exceed $2\frac{1}{2}''$ in even the largest coils, therefore the approximate size of the secondary will be $3\frac{3}{4}''$ bore, $18''$ long and $8''$ in diameter.

In conclusion, it may be of use to make a short summary of the main rules governing the design of induction coils, bearing in mind the necessity of taking a mean value where two conclusions are apparently at variance with one another.

1. The output of the coil should be obtained by multiplying the required voltage by the current required, thereby obtaining the output in volt-amperes.
2. An efficiency of ·3 to ·6 can be allowed, thereby giving the volt-amperes input required.
3. 15 lbs. of iron should be allowed for every 1,000 volt-amperes input.
4. The iron should be so disposed as to have a ratio of length to diameter of about 10.
5. The true magnetic length of the core is the geometrical length, less one diameter.
6. The secondary length should be 80 per cent. of the true magnetic length of the core, that is length of secondary $r = {\cdot}8\,(l-d)$.
7. Diameter of secondary should not exceed 2·5 times its bore.

8. The length of the secondary should be 1·33 times the spark length. No. 8 and No. 4 must thus be reconciled.
9. The length of primary tube should be at least twice the length of the maximum spark, and preferably twice the length of the secondary winding.
10. The number of turns in the secondary can be based from observation, at 5,000 turns per inch of spark, rather less for large coils and more for small.
11. A transformation ratio of 100 to 1 can be used. This can be raised to 150 to 1 for moderately small coils, or lowered 75 to 1 for large coils. Hence the transformation ratio given by the number of turns in the secondary will give
12. The number of turns in the primary, which should almost entirely cover the total core length. Further, it is useful to allow from half to one layer in addition to meet varying conditions.
13. Having determined the requisite number of turns the gauge required in both primary and secondary and the winding length, etc., can be ascertained from the table in Plate VI.
14. The value of the condenser capacity can be approximately determined from curve, Fig. 165, but as this is made for spark lengths of coils for ordinary general purposes, allowances must be made if the coil is to be used for wireless or other heavy current work, and the values thereon given should be approximately doubled.

Appended is a list of coils of various spark lengths.

Several of these have been constructed by the writer, the rest are from various publications which have from time to time appeared, and although details are incomplete in several, comparison of the various proportions is instructive.

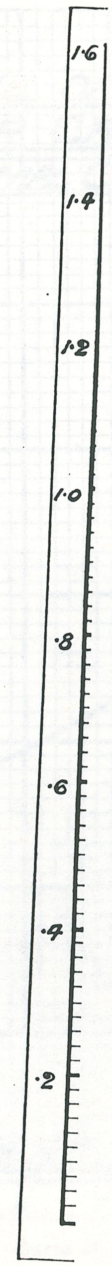

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PLATE XII.

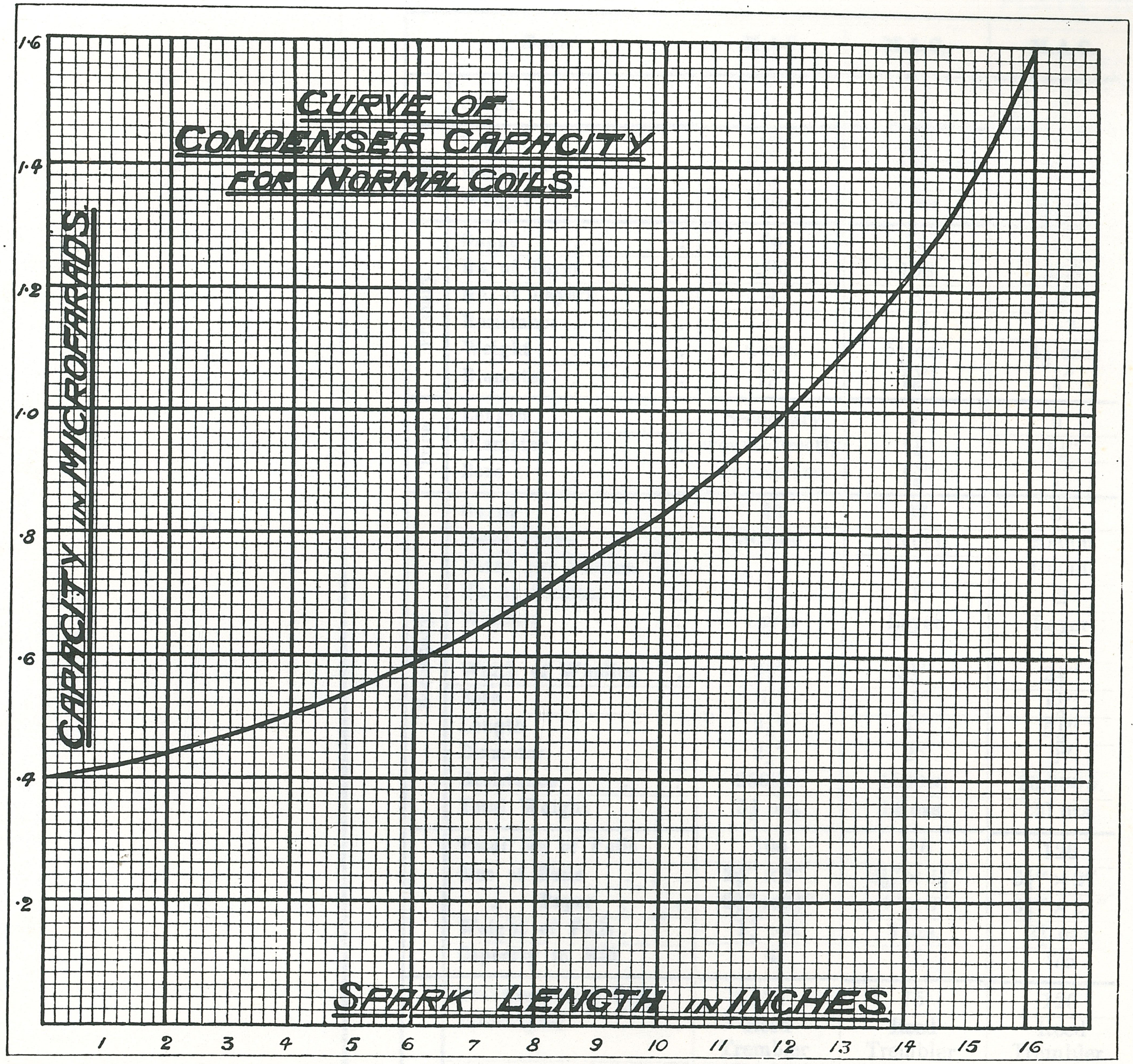

FIG. 165.—Curve of condenser capacity for normal coils.

	Name.	M.A.C.	M.A.C.	M.A.C.
	Spark	$\frac{1}{2}''$	$\frac{3}{4}''$	$1''$
Core.	Length	$4\frac{3}{8}''$	$4\frac{3}{8}''$	$7''$
	Diameter	$\frac{9}{16}''$	$\frac{9}{16}''$	$\frac{5}{8}''$
	Weight	4 ozs.	4 ozs.	$6\frac{1}{2}$ ozs.
Primary.	Gauge	20	18	17
	No. of Turns	290	198	168
	No. of Layers	4	3	2
	Resistance	·5	·19	·12
	Weight	4 ozs.	$5\frac{1}{2}$ ozs.	$4\frac{1}{2}$ ozs.
	Diameter	$\frac{15}{16}''$	$\frac{15}{16}''$	$\frac{7}{8}''$
Tube.	Length	Secondary wound directly on primary.	$4''$	$6''$
	Diameter		$1\frac{1}{8}''$	$1\frac{1}{8}''$
	Bore		$\frac{15}{16}''$	$\frac{7}{8}''$
Secondary.	Gauge	40	37	37
	Total Turns	36,000	15,000	20,000
	Turns per Section	,,	,,	10,000
	No. of Sections	1	1	2
	Winding	Layer	Layer	Layer
	Width of Winding	$2\frac{3}{4}''$	$3\frac{1}{2}''$	$2\frac{1}{4}''$
	Bore	$1''$	$1\frac{1}{8}''$	$1\frac{1}{8}''$
	Length	$3\frac{1}{4}''$	$4''$	$5\frac{1}{2}''$
	Diameter	$2\frac{1}{4}''$	$2''$	$2''$
	Resistance	2500w.	1500w.	20,000w.
	Total Weight	$5\frac{1}{2}$ ozs.	14 ozs.	20 ozs.
	Total No. of Foils	100	150	120
	Size of Foils	$2\frac{3}{8}'' \times 3''$	$2\frac{1}{2}'' \times 3\frac{1}{2}''$	$6\frac{1}{4}'' \times 2''$
	,, Paper	$2\frac{5}{8}'' \times 3\frac{1}{2}''$	$4'' \times 3''$	$6\frac{1}{2}'' \times 2\frac{1}{4}''$
	Weight of Foils	$1\frac{1}{2}$ ozs.	3 ozs.	$2\frac{1}{2}$ ozs.
	Capacity in Mfd.	·4	·7	·75
	Transformation Ratio	124	75	120
	Interrupter	Reed Trembler	Reed Trembler	Reed Trembler
	Volts	4—6	8	10
	Amperes	1 to 4	5	5

To face p. 238. Codd, "Induction Coil Design."]

TABLE OF PROPORTIONS OF VARIOUS COILS.

PLATE XIII.

M.A.C.	M.A.C.	M.A.C.	Bottone.	Bottone.	Marconi.	Eddy.	M.A.C.	Allsop.	Hare.	Collins.
$\frac{3}{4}''$	1″	2″	3″	6″	10″	12″	12″	12″	12″	12″
$4\frac{3}{8}''$	7″	8″	13″	15″	$14\frac{5}{8}''$	24″	24″	19″	18″	26″
$\frac{9}{16}''$	$\frac{5}{8}''$	$\frac{7}{8}''$	$1\frac{1}{4}''$	$1\frac{1}{2}''$	$1\frac{3}{4}''$	$2\frac{1}{8}''$	$1\frac{7}{8}''$	$1\frac{1}{2}''$	$1\frac{11}{16}''$	3″
4 ozs.	$6\frac{1}{2}$ ozs.	17 ozs.			7 lbs. 2 ozs.	—	14 lbs.	8 lbs.	7 lbs. 13 ozs.	38 lbs. 10 ozs.
18	17	17	14	14	12	14	14	12	14	12
198	168	200			360	625	757	—	570	400 calculated
3	2	2	4	4	3	3	3	3	3	2
·19	·12	·18	—	—	·184	—	·717	—	·45	—
$5\frac{1}{2}$ ozs.	$4\frac{1}{2}$ ozs.	9 ozs.	$4\frac{1}{4}$ lbs.	5 lbs.	6 lbs. 14 ozs.	—	$8\frac{1}{2}$ lbs.	—	5 lbs. 13 ozs.	12 lbs. approx.
$\frac{15}{16}''$	$\frac{7}{8}''$	$1\frac{3}{16}''$	2″	$2\frac{1}{4}''$	$2\frac{1}{2}''$	$2\frac{3}{4}''$	$2\frac{1}{2}''$	$2\frac{1}{2}''$	$2\frac{1}{2}''$	$4\frac{1}{8}''$
4″	6″	$7\frac{3}{4}''$	12″	14″	20″	26″	24″	22″	22″	$27\frac{1}{4}''$
$1\frac{1}{8}''$	$1\frac{1}{8}''$	$1\frac{7}{16}''$	$2\frac{1}{2}''$	$2\frac{3}{4}''$	$2\frac{15}{16}''$	$3\frac{1}{2}''$	3″	3″	3″	$4\frac{7}{8}''$
$\frac{15}{16}''$	$\frac{7}{8}''$	$1\frac{3}{16}''$	2″	$2\frac{1}{4}''$	$2\frac{1}{2}''$	$2\frac{3}{4}''$	$2\frac{1}{2}''$	$2\frac{1}{2}''$	$2\frac{1}{2}''$	$4\frac{1}{8}''$
37	37	37	35	36	34	38	32	36	36	38
15,000	20,000	40,000	—	—	50,000	75,256	60,000	—	79,168	—
"	10,000	20,000	—	—	430	1254	5000	—	824	—
1	2	2	6	6	116	60	12	96	96	94
Layer	Layer	Layer	Layer Section	Layer Section	Section	Section	Layer Section	Section	Section	Section
$3\frac{1}{2}''$	$2\frac{1}{4}''$	$2\frac{1}{2}''$	$1\frac{11}{16}''$	$1\frac{11}{16}''$	$\frac{1}{8}''$ bare	$\frac{1}{8}''$	$\frac{5}{8}''$	$\frac{1}{8}''$	$\frac{3}{32}''$	$\frac{1}{8}''$
$1\frac{1}{8}''$	$1\frac{1}{8}''$	$1\frac{7}{16}''$	$2\frac{1}{2}''$	$2\frac{3}{4}''$	3″	$3\frac{3}{4}''$	3″	$3\frac{1}{2}''$	$3\frac{1}{2}''$	5″
4″	$5\frac{1}{2}''$	$7\frac{1}{4}''$	$10\frac{1}{2}''$	$10\frac{1}{2}''$	13″	—	16″	12″	$13\frac{1}{2}$	—
2″	2″	$3\frac{1}{8}''$	$4\frac{1}{2}''$	$5\frac{1}{4}''$	$5\frac{1}{2}''$	6″	$7\frac{1}{4}''$	7″	$6\frac{5}{8}''$	$7\frac{1}{4}''$
1500w.	20,000w.	5200w.	—	—	6500w	—	6800w.	—	18,270	—
14 ozs.	20 ozs.	4 lbs. 2 ozs.	4 lbs.	7 lbs.	16 lbs.	—	18 lbs.	12 lbs.	19 lbs.	18 lbs.
150	120	150	144	144	140	—	70	60	82	2,330
$2\frac{1}{2}''\times3\frac{1}{2}''$	$6\frac{1}{4}''\times2''$	$6\frac{1}{2}''\times3''$	$12''\times6''$	$12''\times6''$	$8\frac{1}{2}''\times18\frac{3}{4}''$	—	$8''\times23''$	$12''\times8''$	$9''\times14''$	$2\frac{1}{2}''\times3\frac{3}{4}''$
$4''\times3''$	$6\frac{1}{2}''\times2\frac{1}{4}''$	$7''\times3\frac{1}{2}''$	$13''\times8''$	$13''\times8''$	$9\frac{1}{4}''\times19\frac{1}{4}''$	—	$8\frac{1}{2}''\times24''$	$11''\times9''$	$15\frac{1}{2}''\times10''$	$3''\times4''$ M.I.C.A.
3 ozs.	$2\frac{1}{2}$ ozs.	$4\frac{1}{2}$ ozs.	—	—	$2\frac{1}{4}$ lbs.	—	$3\frac{1}{2}$ lbs.	—	9 lbs.	4 lbs. 6 ozs.
·7	·75	·8	—	—	1·5	—	1·2	—	·39	5
75	120	200	—	—	139	—	79	—	139	—
Reed Trembler	Reed Trembler	Reed Trembler	Hammer	Hammer	Hammer or Turbine	—	Turbine	Hammer	Hammer	Hammer or Turbine
8	10	12—16	12	16	16—100	110	220	6	12	12—100
5	5	7	—	—	9	12	10	12	—	—

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